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Ground Vibration Test of F-16 Airplane With Initial Decoupler Pylon

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Summary

Prior to initial flight tests, a ground vibration test was conducted on an F-16 airplane loaded on each wing with a one-half full (center bay empty) 370-gal tank mounted on a standard pylon, a GBU-8 store mounted on a decoupler pylon, and an AIM-9J missile mounted on a wing-tip launcher. The decoupler pylon is a passive wing/store flutter-suppression device. Sinusoidal frequency sweeps were performed, and frequency response functions at several locations on the airplane were measured with the decoupler pylon in the centered, nose-up, and bound conditions. The effect of shaker-force level on the decoupler pylon pitch mode was documented.

Rigid-body modes and structural modes were identified. Mode-shape data were taken for six symmetric and six antisymmetric modes, with four additional surveys for variations on these modes. Both pylons are characterized by some lateral free play and large frictional forces. Neither the frictional force nor the lateral free play was unexpected. No other unusual vibratory motion of the pylon or airplane was observed during the test.

Introduction

The Decoupler Pylon Program is a NASA-sponsored program to demonstrate the concept of passive wing/store flutter suppression by reducing the pylon pitch stiffness, so that the store/pylon pitch frequency is less than the fundamental wing-bending frequency. The results of several wind-tunnel tests using model decoupler pylons on three different flutter models are given in reference 1. In each case, it is shown that a properly designed decoupler pylon is able to suppress wing/store flutter.

Based on analyses and wind-tunnel tests of the pylon, a program was defined and initiated for the design, manufacture, and flight test of a decoupler pylon on an F-16 airplane. The results of a feasibility and conceptual-design study are given in reference 2. The design, manufacture, and ground tests of the pair of flight decoupler pylons mounted in a test fixture are documented in reference 3. In preparation for the flight test, a ground vibration test (GVT) was conducted on the F-16 configured on each wing with a fuel tank mounted on a standard pylon, a GBU-8 store mounted on a decoupler pylon, and an AIM-9J missile mounted on a wing-tip launcher, as shown in figure 1. This store combination exhibits antisymmetric flutter when the GBU-8 is carried on a standard pylon. The GVT was conducted as a joint effort by the Dryden Flight Research Facility of the Ames Research Center (Ames-Dryden) and the Langley Research Center, with General Dynamics Corporation/Fort Worth Division providing technical assistance. The test was performed at Ames-Dryden from October 7 to October 14, 1983.

The objectives of the GVT were as follows:

1. To measure the frequencies of aircraft structural modes below 24 Hz.
2. To measure mode shapes for the first three symmetric and antisymmetric structural modes.
3. To observe any unusual vibratory motion of the decoupler pylon and/or airplane.
4. To assess predictive analysis accuracy by comparing measured modal data with predicted data.
5. To measure the effect of shaker-force level on the modal frequencies for the pylon vertical and lateral modes.
6. To measure the pylon vertical and lateral mode frequencies with the pylon positioned against its travel stops.
7. To measure the pylon pitch frequency with a yawing moment applied.

Vehicle Configuration

The flight-test configuration was tested in the Flight Loads Research Facility at Ames-Dryden, as shown in figure 2. The aircraft (serial number 75-0746) was on its landing gear during the ground vibration test. The landing-gear struts were collapsed to eliminate potential nonlinearities in the oleo strut. The tires were deflated to one-half of the normal pressure to provide a soft support. Electrical and hydraulic power were applied to the aircraft, and the control system was on during the test to trim the control surfaces to their neutral position. Air conditioning was externally supplied to cool the electronics.

The aircraft fuel loading for the test was full fuselage tanks, full wing tanks, and one-half full (center bay empty) 370-gal external fuel tanks. As a safety measure, the fuel tanks were pressurized with nitrogen gas to provide an inert atmosphere.

The decoupler pylon, as illustrated in figure 3, incorporates an upper part fixed to the wing and a movable lower part to which the store is attached. Key features of the decoupler pylon are a four-bar-linkage mechanism, a damper, a spring, and an alignment device. The spring stiffness is such that the pylon pitch mode frequency is below the antisymmetric first wing-bending mode. Ground tests indicated that high frictional forces exist in the pylon, and therefore, the damper is not required for flight. For this reason, the viscous fluid in the damper was removed. The pylon alignment system consists of an electric motor with a gear box, off-on switches, and travel limit switches. The alignment system operates only on the static pitch position of the store. The off-on switches activate the alignment motor when the store becomes misaligned from its nominal position by more than ±0.5°. The physical pitch limits of the pylon are ±3°. If the alignment system malfunctions, travel limit switches deactivate the alignment motor prior to contacting the physical limits.

The airplane was tested with the pylon and GBU-8 store in three different conditions. These conditions were

1. The pylon/GBU-8 store in the null or trimmed position.
2. The pylon/GBU-8 store positioned against the nose-up electrical stop limit.
3. The pylon/GBU-8 store in the null or trimmed position and a 700-lbf side force applied 34 in. forward of the GBU-8 store center of gravity. This caused binding of the pylon mechanism.

Test Equipment

Ames-Dryden GVT equipment was used for the test. The excitation system consisted of four electrodynamic shakers (two 50 lbf and two 150 lbf), four power amplifiers with independent gain and phase control, and a sweep oscillator for a function generator. Response-measuring equipment consisted of six piezoelectric accelerometers with associated signal conditioning, six tracking filters, one XY scope, two four-channel Yt scopes, three XYY plotters, an eight-channel strip-chart recorder, a frequency counter, and a digital voltmeter. A co/quad analyzer was used for tuning modes.

Test Procedures

Excitation

Single and multishaker techniques were used to excite the airplane rigid-body and elastic modes. At all shaker locations, electrodynamic shakers were used to input a sinusoidal forcing function to the structure. The shaker configurations are listed in table I. Typical shaker setups are presented in figures 4 and 5.

Each shaker was attached to the airplane by means of a telescoping thrust rod and a mechanical fuse. The fuse attached to a locking ball nut joint, which was either mounted directly to the structure by a threaded stud or bonded to the structure. These components are shown in figure 6.

Frequency Sweeps

The frequency sweeps were from 2 to 10 Hz or from 2 to 24 Hz with a linear sweep rate of 0.05 or 0.1 Hz/sec. Accelerometers were placed at several locations and in various orientations. Frequency response plots of these accelerometers were recorded on XYY plotters.

Structural Mode Measurement

Modal tuning criterion. After the frequency sweeps were completed, each aircraft structural mode was finely tuned by using a co/quad analyzer with acceleration and force signals as inputs. Each mode was tuned by minimizing the coincident component and maximizing the quadrature component. Time history traces of acceleration were used to measure phasing between the left and right sides of the airplane. A check on the purity of the mode was made by terminating electrical power to the shaker and observing the decay of the oscillations for beats. The absence of beats in the decay trace indicates that a mode is properly tuned.

Modal survey. Once a mode was tuned, roving accelerometers were used to perform a modal survey in which amplitudes were measured at several points on each wing. These points are shown in figures 7 and 8. The point with the largest amplitude reading was selected as the reference point on the structure. The reference was used to normalize all other accelerometer response values and to determine phase relationships with roving accelerometers. Each roving accelerometer was placed at the reference point before the survey to compare amplitude readings. The accelerometer amplifier gains were adjusted as necessary to insure uniform readings. Some modes were surveyed completely, whereas other modes were surveyed only to the extent that they could be identified.

Pylon Position

Ground test data from General Dynamics indicated that the pylon pitch stiffness depended on the GBU-8 store position. The position with the pylon nose-up against the physical stop was considered the most critical because the pitch stiffness in this position was greater than the stiffness of the production weapons pylon. Subsequent to the General Dynamics tests, the alignment system limit switches were set so that the pylon would not contact the physical stops. Thus for this test, the pylon was at its nose-up electrical limit.

Pylon Preload

One of the objectives of the GVT was to determine mode frequencies and mode shapes when the pylon was bound with a combined side load and yawing moment. A combined side load and yawing moment was applied to each GBU-8 store, as shown in figure 9. A 700-lbf load was applied 34 in. forward of the store center-of-gravity by using a hydraulic ram attached to 3/8-in. bungee chord. A load cell was used to measure the input force.

At another time during the test, a much smaller lateral load of 80 lbf was applied to each GBU-8 by means of bungee chord. This load was intended to reduce the effects of lateral free play.

Results and Discussion

Rigid-Body Modes

The rigid-body modes of the airplane supported on its landing gear were measured. These modes included pitch, roll, lateral translation, and a combination yaw/roll mode. The vertical translation mode could not be excited. The measured rigid-body frequencies are as follows:

Mode	Frequency, Hz
Roll	1.34
Pitch	2.03
Yaw/roll	2.36
Lateral translation	3.59

Structural Modes

Frequency sweeps. Multishaker frequency sweeps were performed at several force levels and at several locations. Symmetric sweeps and antisymmetric sweeps were performed to identify approximate frequencies of modes. Twenty-one sweeps were performed. These data are presented in appendix A.

Mode identification. Structural modes were identified by their frequencies and mode shapes. Table II lists the modes that were identified and gives a comparison of the measured and predicted mode frequencies. A complete or partial modal survey was performed on these modes. The measured mode shapes are presented in appendix B.

Analysis/Test Correlation

Predicted mode frequencies and mode shapes were available from a vibration analysis for the plane in a free-free state with no internal wing fuel and with frictionless decoupler pylons. The plane as tested was supported on its landing gear and had full internal wing fuel. Also, the pylons have significant friction. Even with these differences, all the measured mode frequencies were within 6 percent of the predicted values except for three modes. Comments on the modes of interest are given in the following sections.

GBU-8 pitch modes. The measured symmetric (4.08 Hz) and antisymmetric (3.92 Hz) pitch modal frequencies were 25 and 22 percent higher, respectively, than the predicted frequencies. Frictional forces could account for this difference. Ground tests at General Dynamics in Fort Worth, Texas, had indicated that significant friction exists in the pylon four-bar-linkage bushings, and that each pylon had a different amount of damping (ref. 3). During the current test, a shaker force of approximately 70 lbf at the nose of the store was required to break the pylons out of the friction band, so that the pylons were decoupled. The pylons were determined to be decoupled by visually observing the motion between the upper and lower portion of each pylon. The decay traces obtained from the GBU-8 accelerometers indicated that the right pylon (serial number 001) had approximately twice the damping due to friction as the left pylon (serial number 002). These results correlate with the results obtained at General Dynamics.

With the pylon at its nose-up alignment system limit, the measured frequencies were 4.14 Hz for the symmetric mode and 4.00 Hz for the antisymmetric mode. These measured frequencies were approximately 2 percent higher than the frequencies obtained with the GBU-8 centered. The pylon alignment motor travel limit switches had been set such that the nose-up position of the pylon/GBU-8 store did not contact a hard travel stop. The measured frequencies indicate that at this position the pylon pitch stiffness was generally the same as the stiffness with the pylon/GBU-8 store centered. However, when the pylon was bound because of the applied load and yawing moment, the pylon pitch mode had a higher frequency. The measured symmetric and antisymmetric frequencies for this condition were 4.68 Hz and 4.51 Hz, respectively.

Shaker force was determined from the shaker feedback current. The effect of shaker-force level on the GBU-8 pitch frequency for the pylon/GBU-8 store in the nominal position, for the store in the alignment system nose-up position, and for the pylon in a bound condition is shown in figures 10, 11, and 12, respectively. In general, the data indicated that as the force level was increased, the frequency decreased slightly. Also shown in figure 10 are the force level and frequency tuned for the modal survey.

GBU-8 lateral modes. One of the results of the efforts to reduce the pylon frictional forces was an increase in the lateral free play (ref. 3). The vibration analysis, which does not account for free play, predicted two lateral symmetric and three antisymmetric modes close in frequency (table II) but having different mode shapes. These modes were difficult to tune, and the left-to-right phasing was poor because of the free play in the pylon four-bar-linkage bushings. As a consequence, the left and right sides of the airplane had to be tuned separately. The association of a measured frequency with the predicted frequency was made after comparing measured and predicted mode shapes. It was not possible to tune each lateral mode. The two lateral modes not tuned were the symmetric 5.12-Hz mode and the antisymmetric 6.20-Hz mode. Also, the 5.21-Hz mode could not be tuned on the left side of the airplane. Similar difficulties in modal tuning have been encountered in ground vibration tests of other airplanes with store lateral free play (ref. 4).

When frequency sweeps were performed on the pylons with an 80-lbf preload, the frequency responses of the symmetric modes (fig. A8) and the antisymmetric modes (fig. A19) were not significantly changed. Therefore, no mode shape data were taken with this preload.

The effect of shaker-force level on two of the GBU-8 lateral modal frequencies is shown in figure 13. There is a general trend of decreasing frequency with increasing input force, but the results are not conclusive.

The lateral modes with the pylon in the nose-up position were not obtained because the previously determined vertical modes were not strongly influenced by having the pylon in this position.

Symmetric wing-bending mode. The measured wing-bending frequency (3.02 Hz) was 18.2 percent lower than the predicted frequency (3.69 Hz). This difference can be attributed to the difference in internal wing fuel loading and suspension between analysis and experiment. Subsequent taxi tests (airplane on gear but empty internal wing fuel tanks) indicated that the symmetric first wing-bending frequency was approximately 3.5 Hz. Initial flight-test results (airplane with empty internal wing fuel tanks and in the free-free state) indicated that the symmetric first wing-bending mode was approximately 3.6 Hz.

Concluding Remarks

Prior to initial flight tests, a ground vibration test was conducted on an F-16 airplane loaded on each wing with a one-half full (center bay empty) 370-gal tank mounted on a standard pylon, a GBU-8 store mounted on a decoupler pylon, and an AIM-9J missile mounted on a wing-tip launcher. The decoupler pylon is a passive wing/store flutter-suppression device. Sinusoidal frequency sweeps were performed from 2 to 24 Hz. Frequency response functions at several locations on the airplane were measured with the decoupler pylon in the centered, nose-up, and bound conditions.

Rigid-body modes and structural modes were identified. Mode-shape data were taken for six symmetric and six antisymmetric modes, with four additional surveys for variations on these modes. All the measured structural mode frequencies were within 6 percent of the predicted frequencies except for the symmetric first wing bending (18 percent low) and the symmetric and antisymmetric pylon pitch (25 and 22 percent high, respectively). The wing-bending frequency difference is the result of wing fuel loading and gear constraint differences between the plane and the analytical model. The pylon pitch mode difference is probably the result of friction in the pylon. Both pylons exhibit large frictional forces. A shaker force of 70 lbf was required at the nose of the store to overcome frictional forces and to allow the pylon to move. The frequency of the pitch mode when the store was nose-up at the switch limits of the alignment system was essentially the same as when the store was centered. Because of this, the lateral modes were not measured for this condition. When the pylon was bound by applying an external yawing moment, the pylon pitch frequency increased. The frequency of the GBU-8 pitch mode decreases with increasing shaker-force level whether the pylon is centered, bound, or nose-up at the electrical stops. The lateral free play in the pylons affected the lateral store modes. These modes were characterized by poor left-to-right phasing, and as a consequence, each side of the airplane was tuned separately. In addition, it was not possible to tune several modes which had been indicated analytically.

Neither the frictional force nor the lateral free play was unexpected, both having been observed in previous ground tests. No other unusual vibratory motion of the pylon or airplane was observed during the test.

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TABLE I. SHAKER CONFIGURATIONS

Configuration	Shakers			
	No.	Force rating, lbf	Location	Direction
1	1	150	Forward fuselage jack point	Vertical
2	2	50	Wing, forward launcher	Vertical
3	2	50	Wing, aft launcher	Vertical
4	2	150	GBU-8, forward	Vertical
5	2	150	GBU-8, forward	Lateral
6	2	150	GBU-8, forward	Lateral
	2	50	GBU-8, aft	Lateral

TABLE II. MODAL FREQUENCIES AND STRUCTURAL DAMPING COEFFICIENTS

Mode	Symmetric				Antisymmetric			
	Analysis frequency, Hz	GVT frequency, Hz	Percent difference[a]	Damping coefficient, g	Analysis frequency, Hz	GVT frequency, Hz	Percent difference[a]	Damping coefficient, g
1st wing bending	3.694	3.02	−18.2	0.039	8.720	8.71	−0.1	0.028
2nd wing bending	9.982	9.77	−2.1					
Tip missile pitch	5.955	6.27	5.3		5.543	5.32	−4.0	
Missile pitch/wing bending	6.606							
370-gal tank pitch	7.381	7.49	1.5		7.113	7.35	3.3	
1st 370-gal tank yaw	7.923				7.981			
2nd 370-gal tank yaw	14.175				12.882			
GBU-8 pitch (nominal)	3.259	4.08	25.2	0.037 (left), 0.073 (right)	3.216	3.92	21.9	0.046 (left), 0.096 (right)
GBU-8 pitch (nose-up limit)		4.14				4.00		
GBU-8 pitch (pylon binding)		4.68		0.041		4.51		0.055
1st GBU-8 lateral	5.123				4.901	4.75 (left), 4.82 (right)	−3.1 (left), −1.7 (right)	
2nd GBU-8 lateral	5.309	5.26 (left), 5.21 (right)	−0.92 (left), −1.9 (right)		5.211	5.29 (right)	1.5 (right)	
3rd GBU-8 lateral					6.021			
Vertical tail bending					11.735	11.91	1.5	

[a]Percent difference = $100\left(\frac{\text{GVT frequency}}{\text{Analysis frequency}} - 1\right)$.

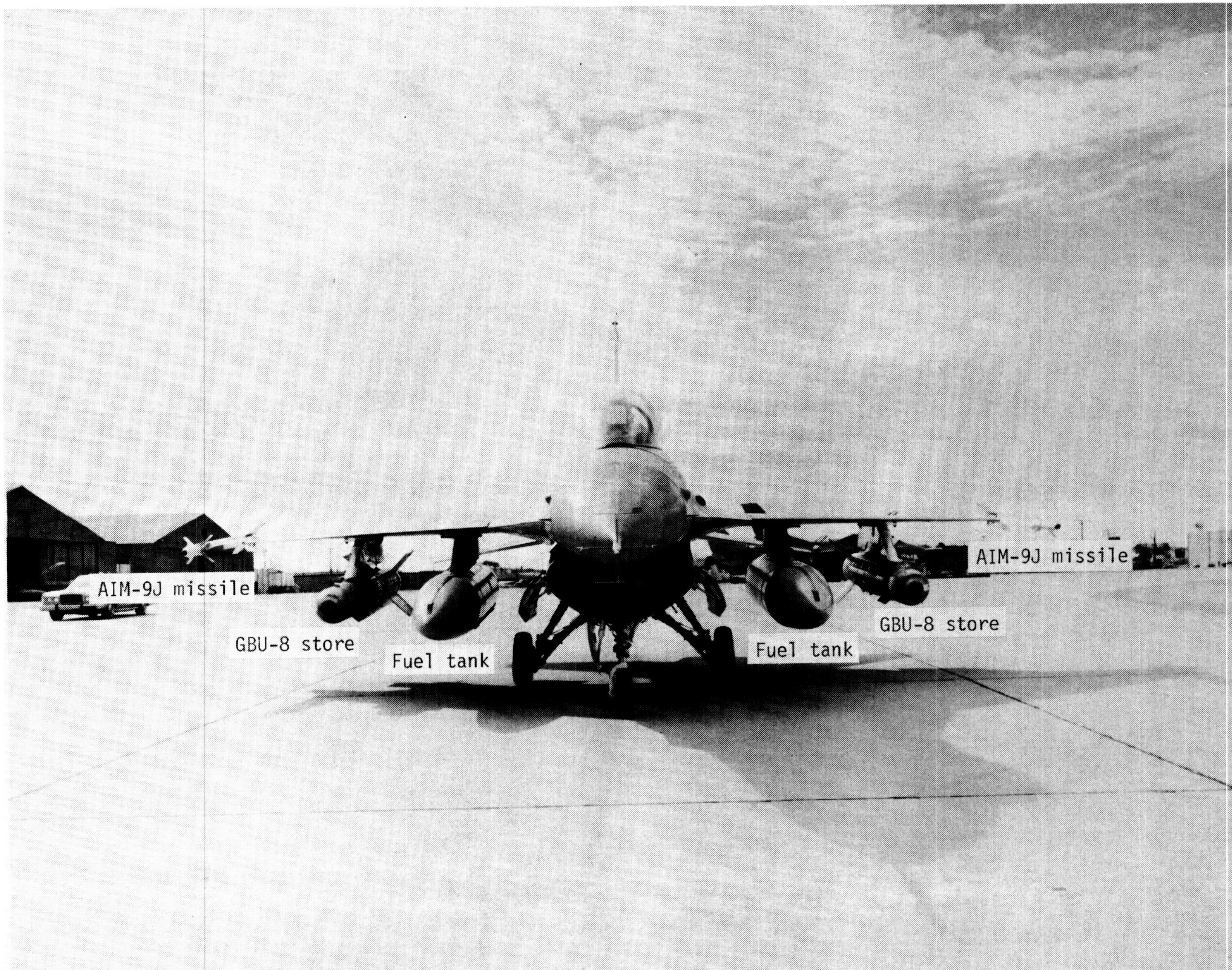

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Figure 1. Airplane with test stores.

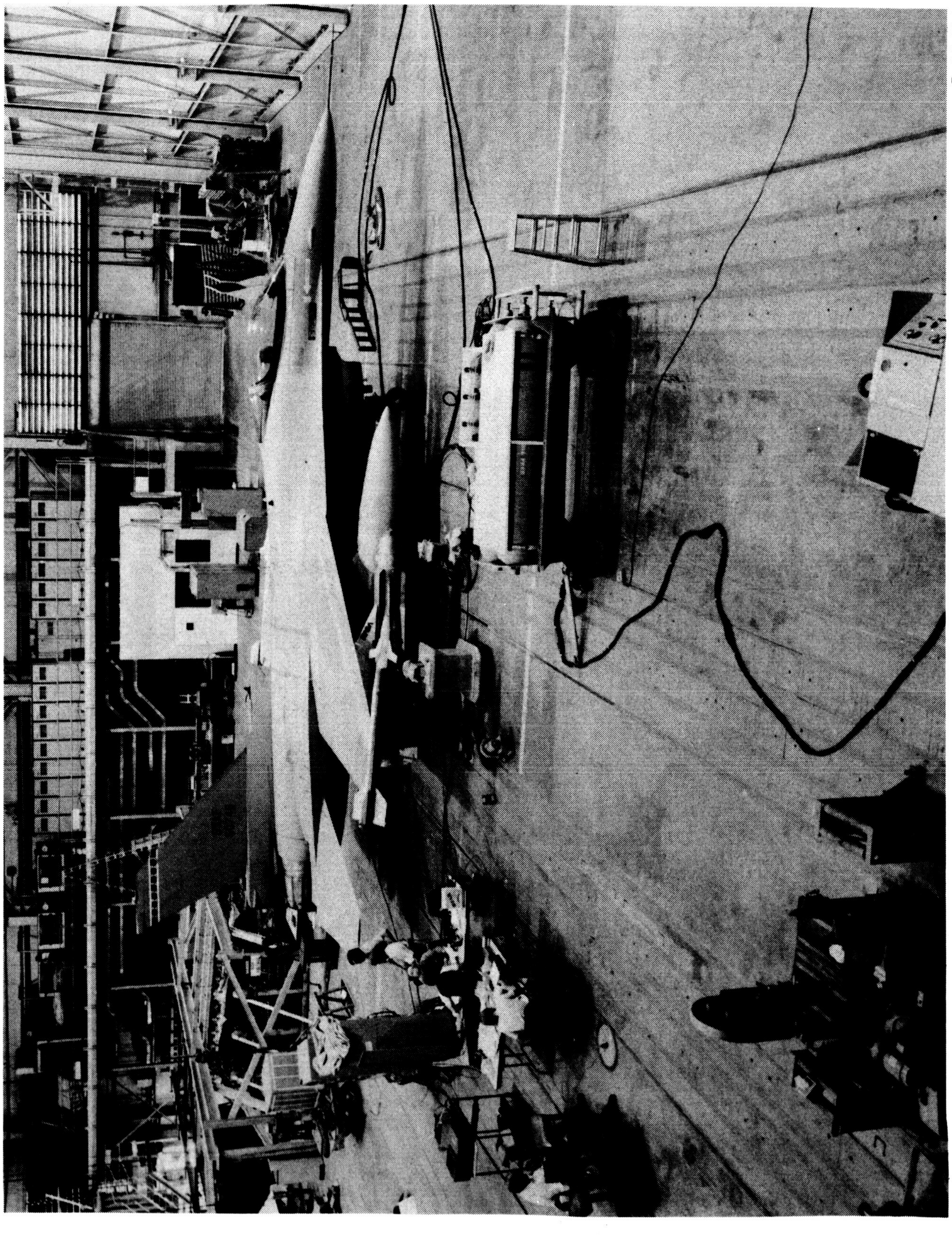

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Figure 2. Airplane ground vibration test setup.

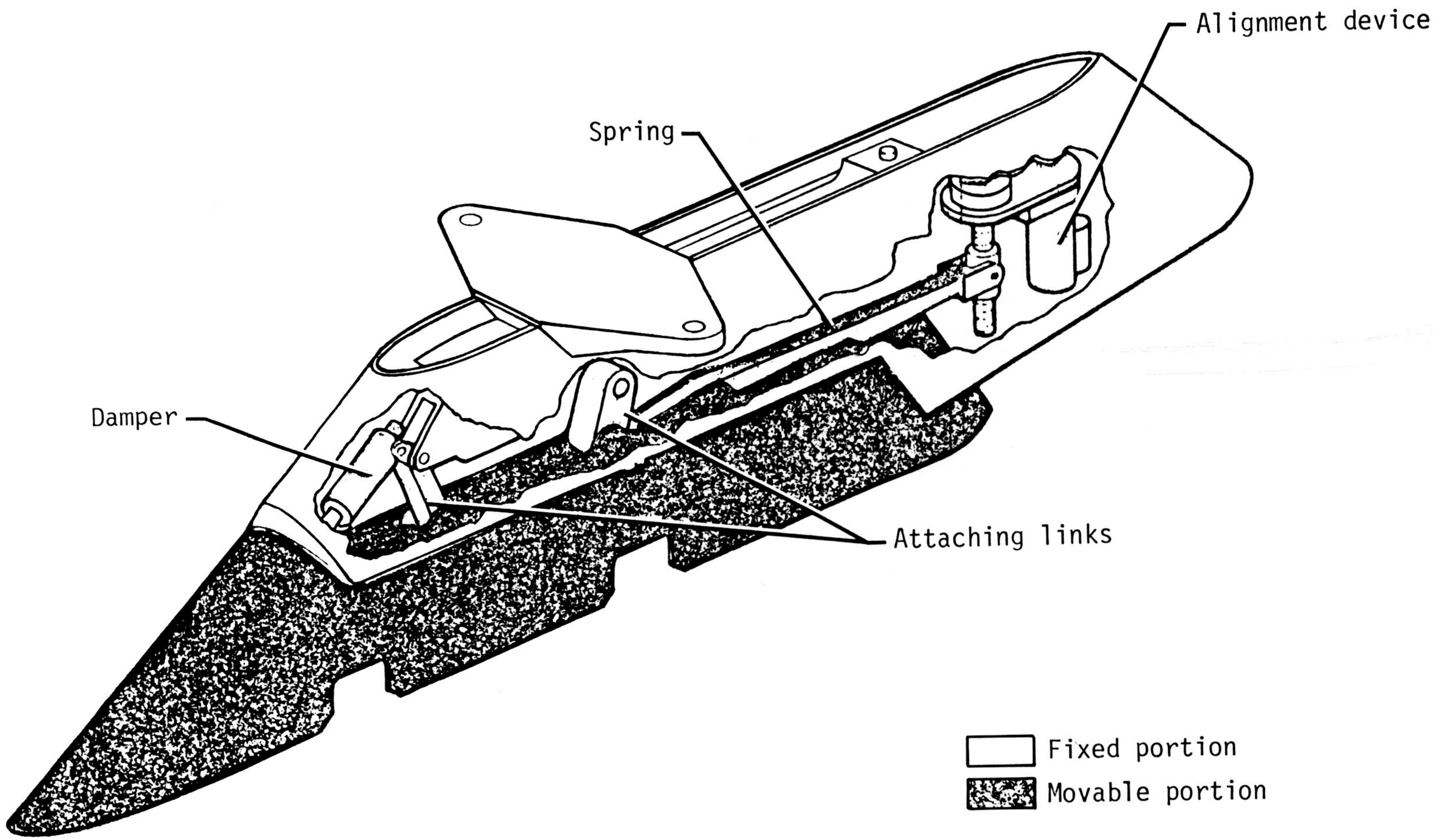

Figure 3. Decoupler pylon components.

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Figure 4. Wing-tip missile launches and GBU-8 store shaker locations.

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Figure 5. GBU-8 store lateral dual shaker location (configuration 6).

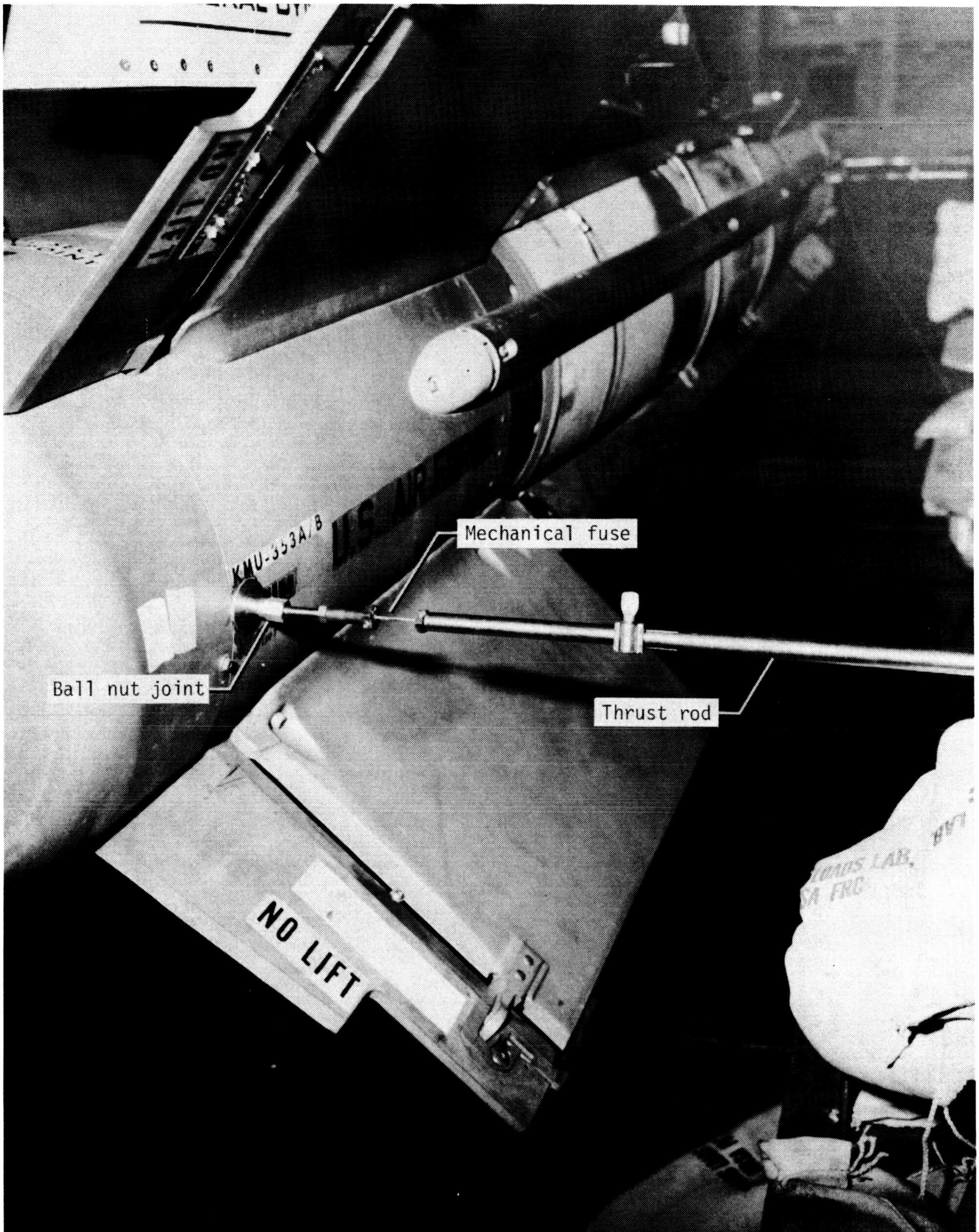

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Figure 6. Shaker attachment hardware.

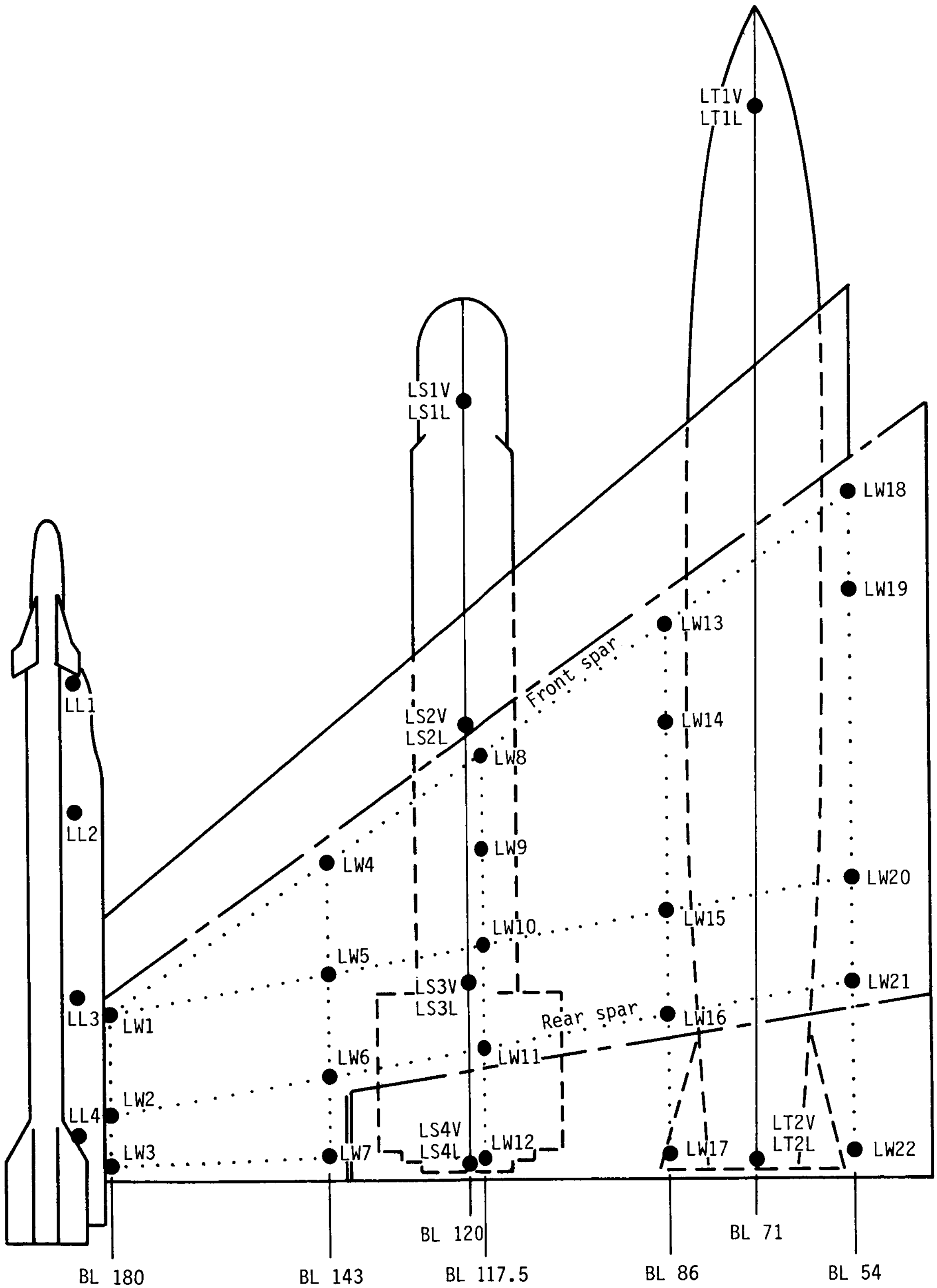

Figure 7. Left wing survey points. BL denotes buttock line.

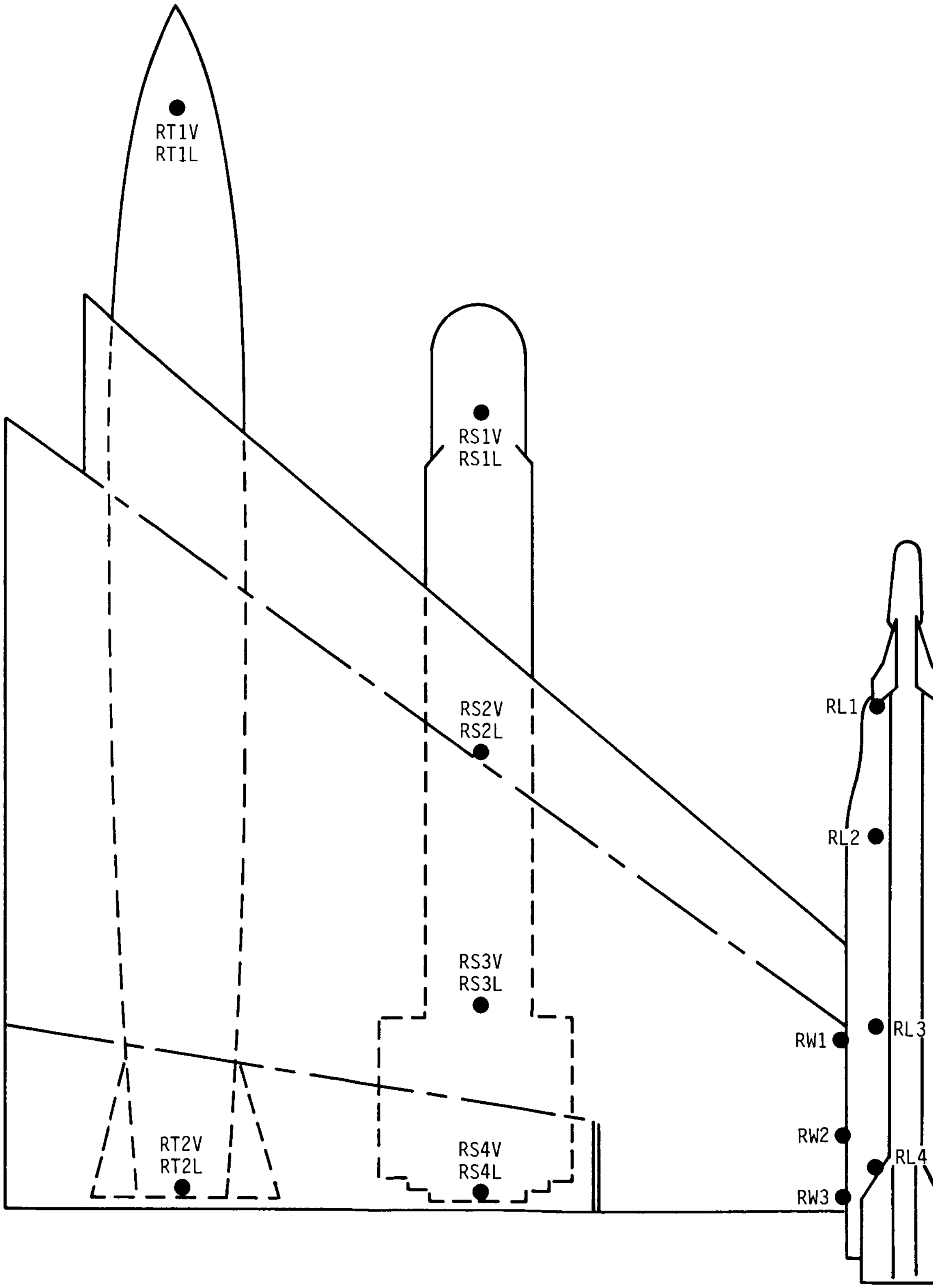

Figure 8. Right wing survey points.

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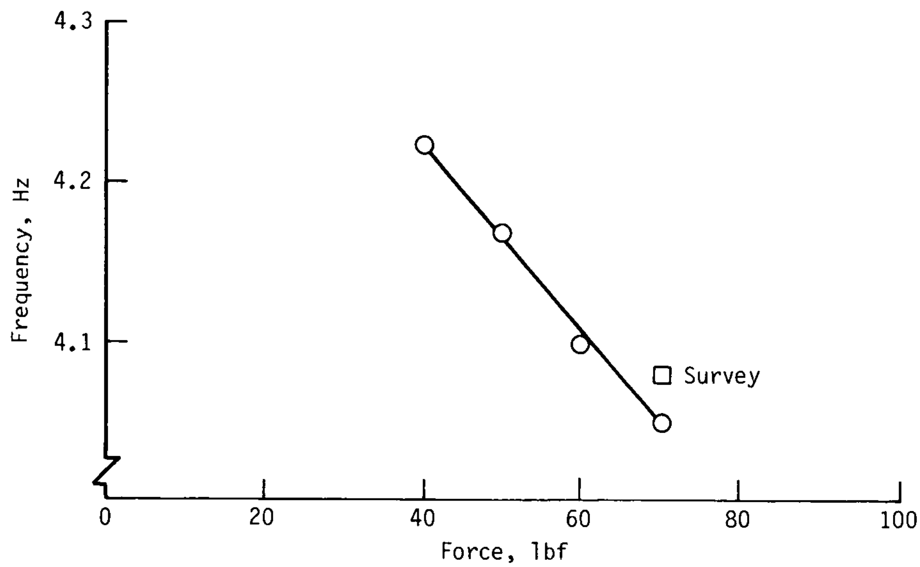
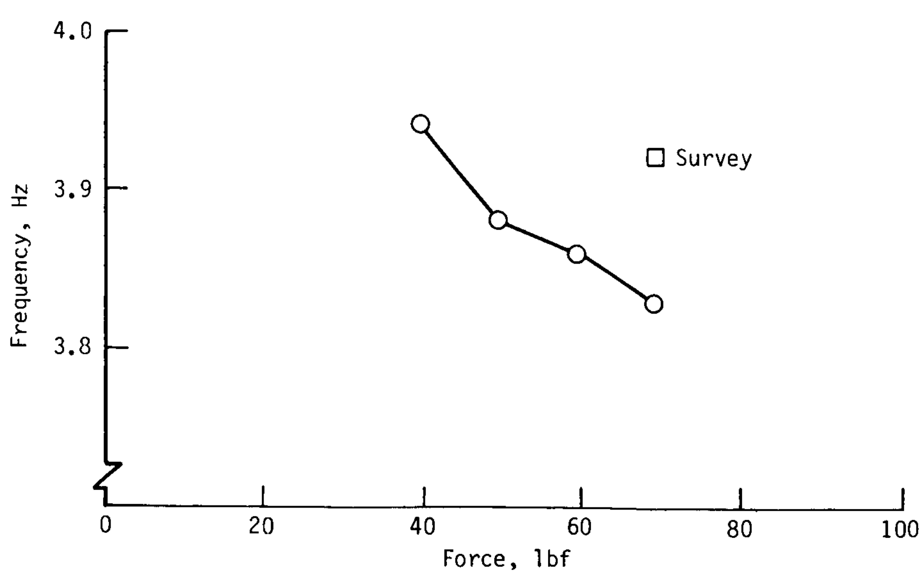
Figure 9. Test setup for pylon preloading.

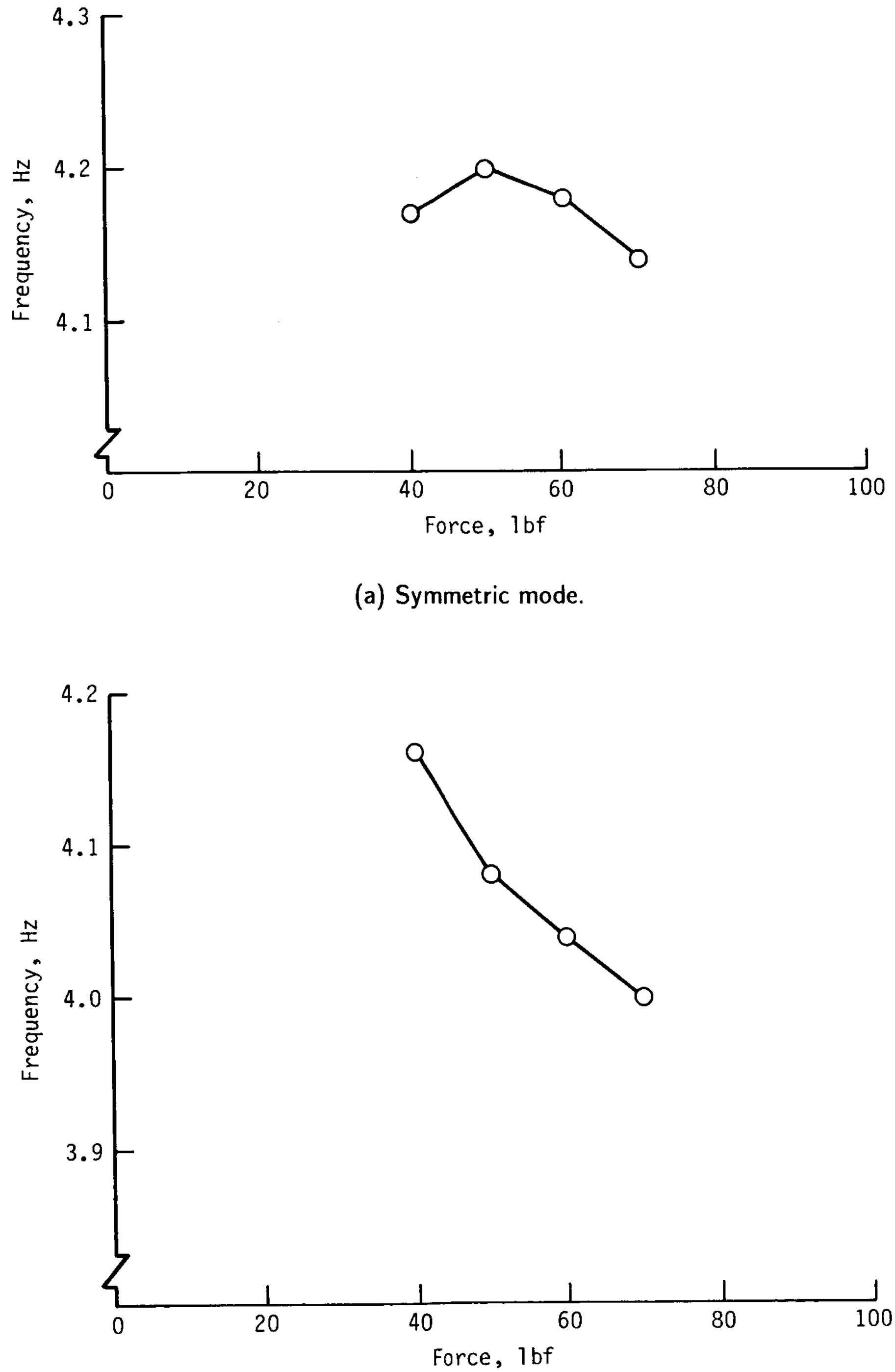


(a) Symmetric mode.



(b) Antisymmetric mode.

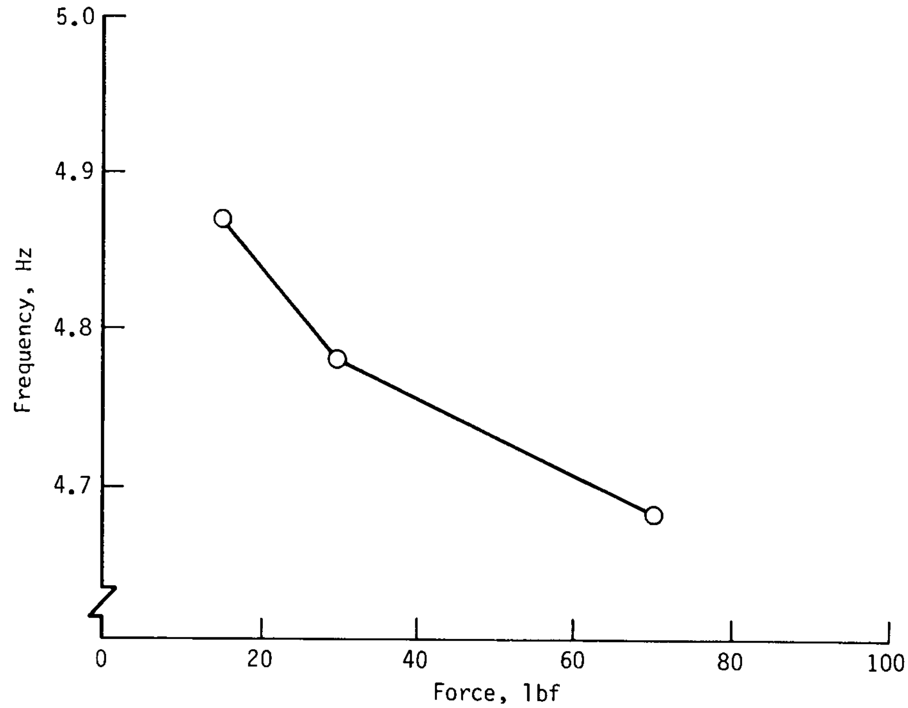
Figure 10. Effect of shaker-force level on frequency of GBU-8 pitch mode for pylon in nominal position.



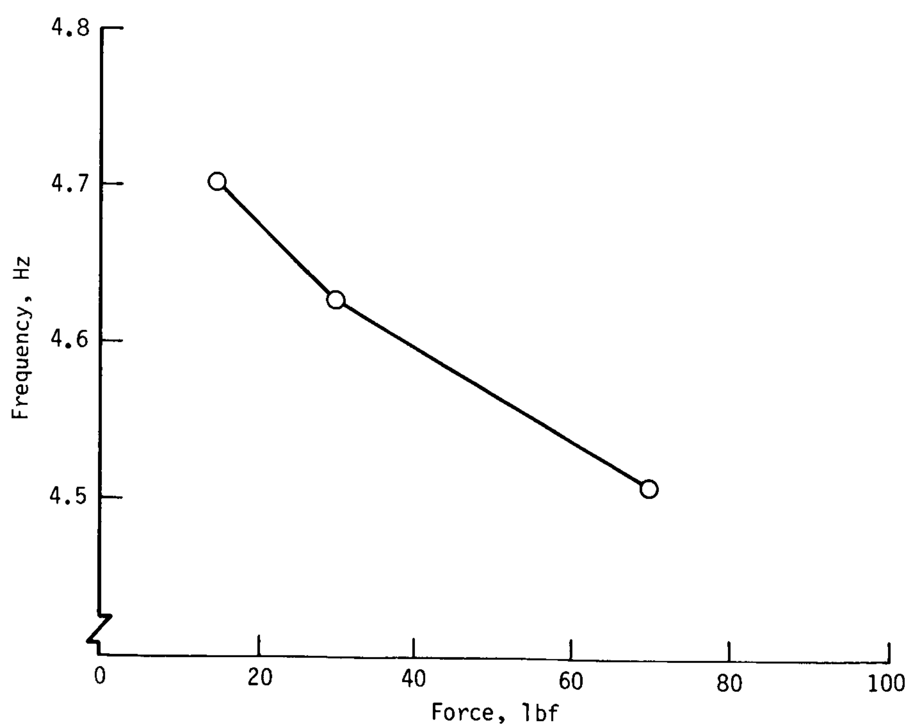
(a) Symmetric mode.

(b) Antisymmetric mode.

Figure 11. Effect of shaker-force level on frequency of GBU-8 pitch mode for pylon in nose-up position.

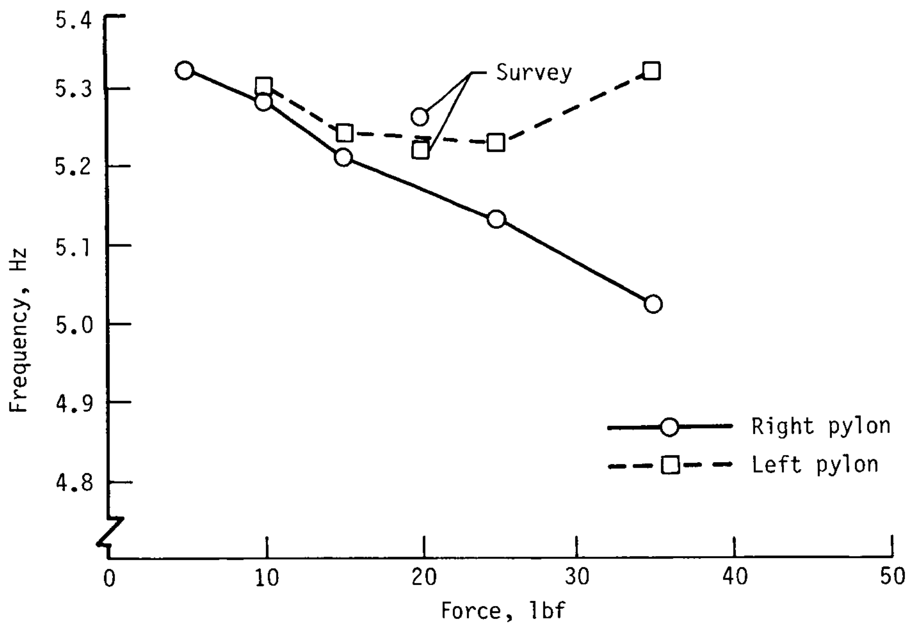


(a) Symmetric mode.

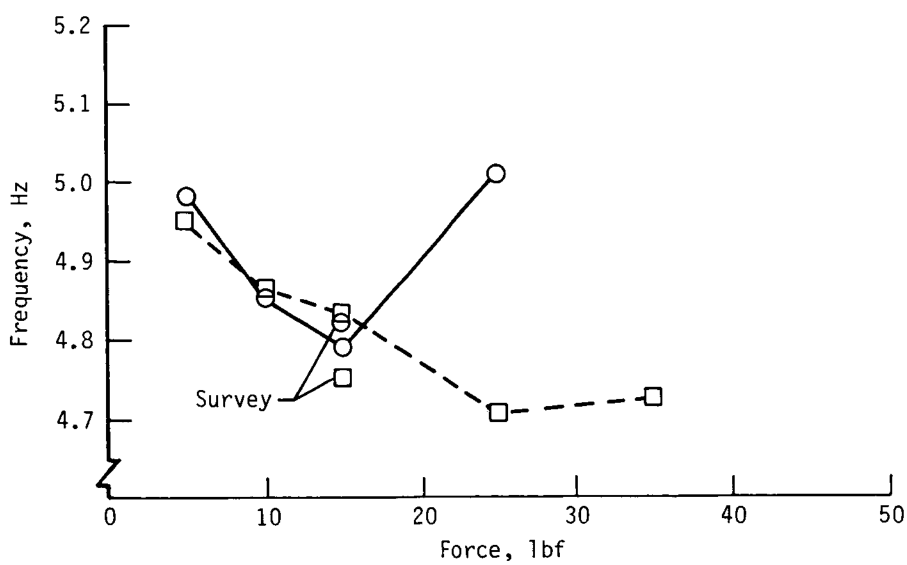


(b) Antisymmetric mode.

Figure 12. Effect of shaker-force level on frequency of GBU-8 pitch mode for pylon in bound condition.



(a) Symmetric mode.



(b) Antisymmetric mode.

Figure 13. Effect of shaker-force level on frequency of GBU-8 lateral mode for pylon in nominal position.

Appendix A

Frequency Sweep Plots

This appendix contains the frequency sweep data obtained during the test. The plots were recorded with a linear sweep rate of 0.1 Hz/sec unless otherwise noted. Table A1 summarizes all the sweeps presented. Listed in the table are the shaker locations, directions, and forces; the excitation symmetries; the response accelerometer locations; and the pylon configurations. The response accelerometer locations, shown in figures 7 and 8, are designated as follows: LL1 to LL4, LS1V to LS4V, LT1V and LT2V, and LW1 to LW22 are vertical survey points on the left launcher, store, tank, and wing, respectively; LS1L to LS4L, and LT1L and LT2L are lateral survey points on the left store and tank, respectively; RL1 to RL4, RS1V to RS4V, RT1V and RT2V, and RW1 to RW3 are vertical survey points on the right launcher, store, tank, and wing, respectively; and RS1L to RS4L, and RT1L and RT2L are lateral survey points on the right store and tank, respectively.

The frequency sweeps are contained in figures A1 through A21. Figures A1 through A10 are the symmetric sweeps, and figures A11 through A21 are the antisymmetric sweeps. The airplane was excited with two shakers for all sweeps except those shown in figures A9, A10, A20, and A21, where all four shakers were used.

TABLE A1. FREQUENCY SWEEP SUMMARY

Fig.	Shaker location	Direction	Force, lbf	Excitation	Response location[a]	Pylon configuration
A1	Launcher, forward	Vertical	15	Symmetric	LL1, RL1	Nominal
A2	Launcher, aft	Vertical	15	Symmetric	LW2, LL3, LS1V, RW2, RL3	Nominal
A3	GBU-8, forward	Vertical	57	Symmetric	LW2, LS1V, RT1V, RL1, RW2, RS1V	Nominal
A4	GBU-8, forward	Vertical	40, 70	Symmetric	LS1V, RS1V	Nominal
A5	GBU-8, forward	Vertical	40, 70	Symmetric	LS1V, RS1V	Nose-up at limit
A6	GBU-8, forward	Vertical	70	Symmetric	LS1V, RS1V	Bound with 700-lbf preload
A7	GBU-8, forward	Lateral	15, 25	Symmetric	LS1L, RS1L	Nominal
A8	GBU-8, forward	Lateral	15, 25	Symmetric	LS1L, RS1L	80-lbf preload
A9	GBU-8, forward & aft	Lateral	10	Symmetric (roll)	LS1L, RS1L	Nominal
A10	GBU-8, forward & aft	Lateral	10	Symmetric (yaw)	LS1L, RS1L	Nominal
A11	Launcher, forward	Vertical	15	Antisymmetric	LL1, RL1	Nominal
A12	Launcher, aft	Vertical	15	Antisymmetric	LW2, LL3, RW2, RL3	Nominal
A13	GBU-8, forward	Vertical	57	Antisymmetric	LS1V, RW2, RL1, RT1V	Nominal
A14	GBU-8, forward	Vertical	40, 60, 70	Antisymmetric	LS1V, RS1V	Nominal
A15	GBU-8, forward	Vertical	70	Antisymmetric	LS1V, RS1V	Nominal
A16	GBU-8, forward	Vertical	40, 70	Antisymmetric	LS1V, RS1V	Nose-up at limit
A17	GBU-8, forward	Vertical	70	Antisymmetric	LS1V, RS1V	Bound with 700-lbf preload
A18	GBU-8, forward	Lateral	15, 25	Antisymmetric	LS1L, RS1L	Nominal
A19	GBU-8, forward	Lateral	15, 25	Antisymmetric	LS1L, RS1L	80-lbf preload
A20	GBU-8, forward & aft	Lateral	10	Antisymmetric (roll)	LS1L, RS1L	Nominal
A21	GBU-8, forward & aft	Lateral	10	Antisymmetric (yaw)	LS1L, RS1L	Nominal

[a]See figures 7 and 8 for diagrams of response locations.

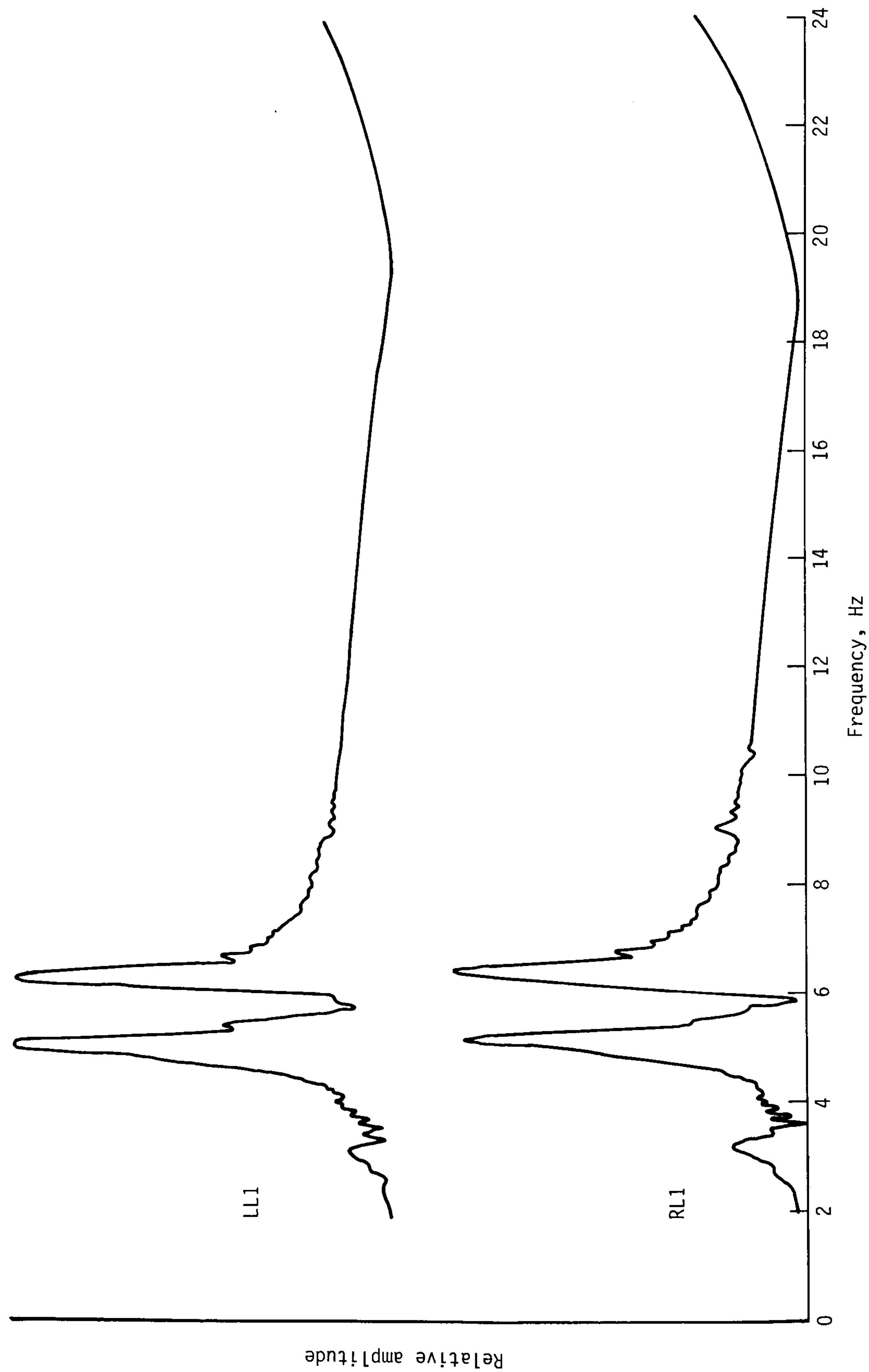


Figure A1. Frequency sweep plot for symmetric vertical excitation, launcher forward shaker location, and force level of 15 lbf.

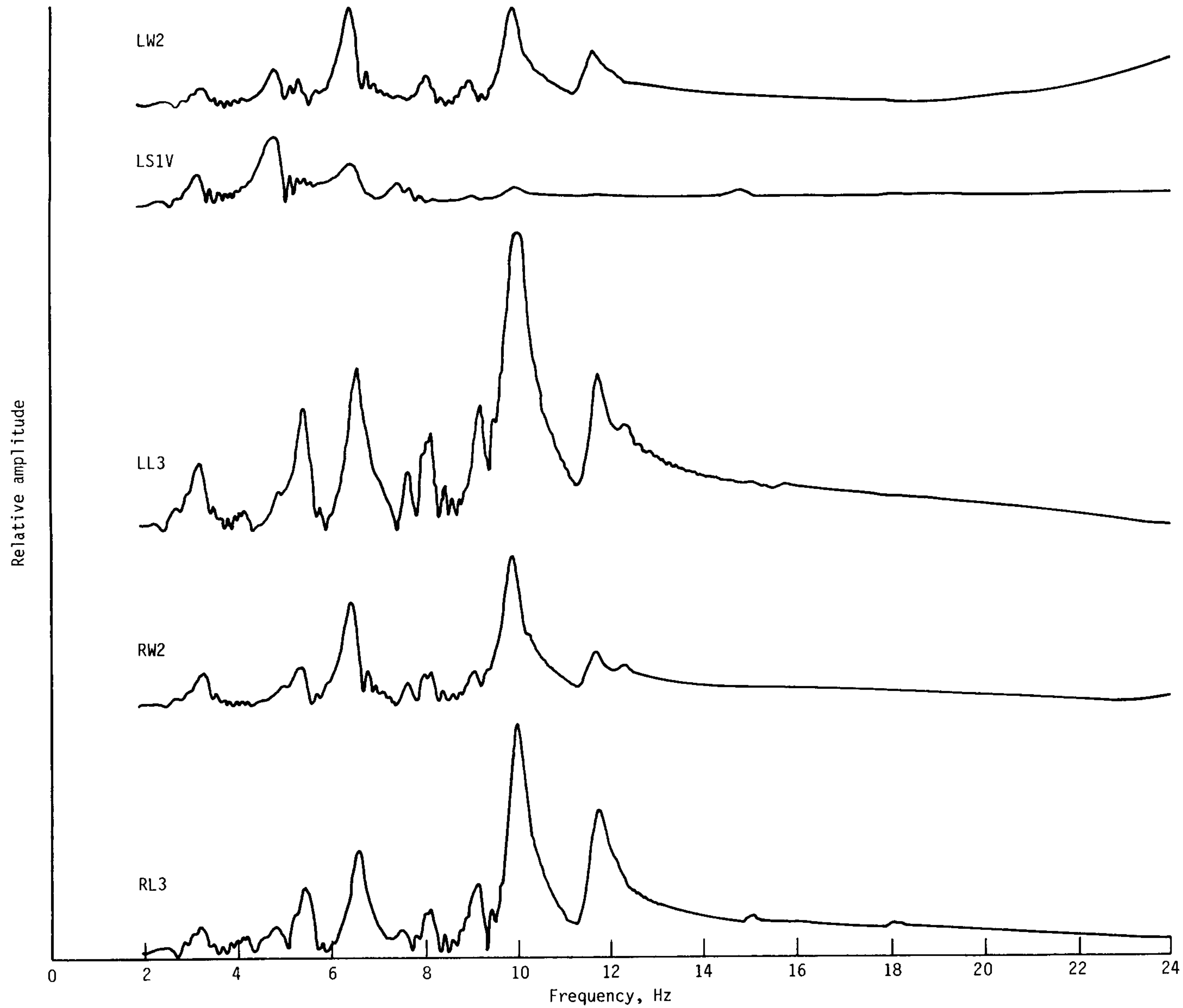


Figure A2. Frequency sweep plot for symmetric vertical excitation, launcher aft shaker location, and force level of 15 lbf.

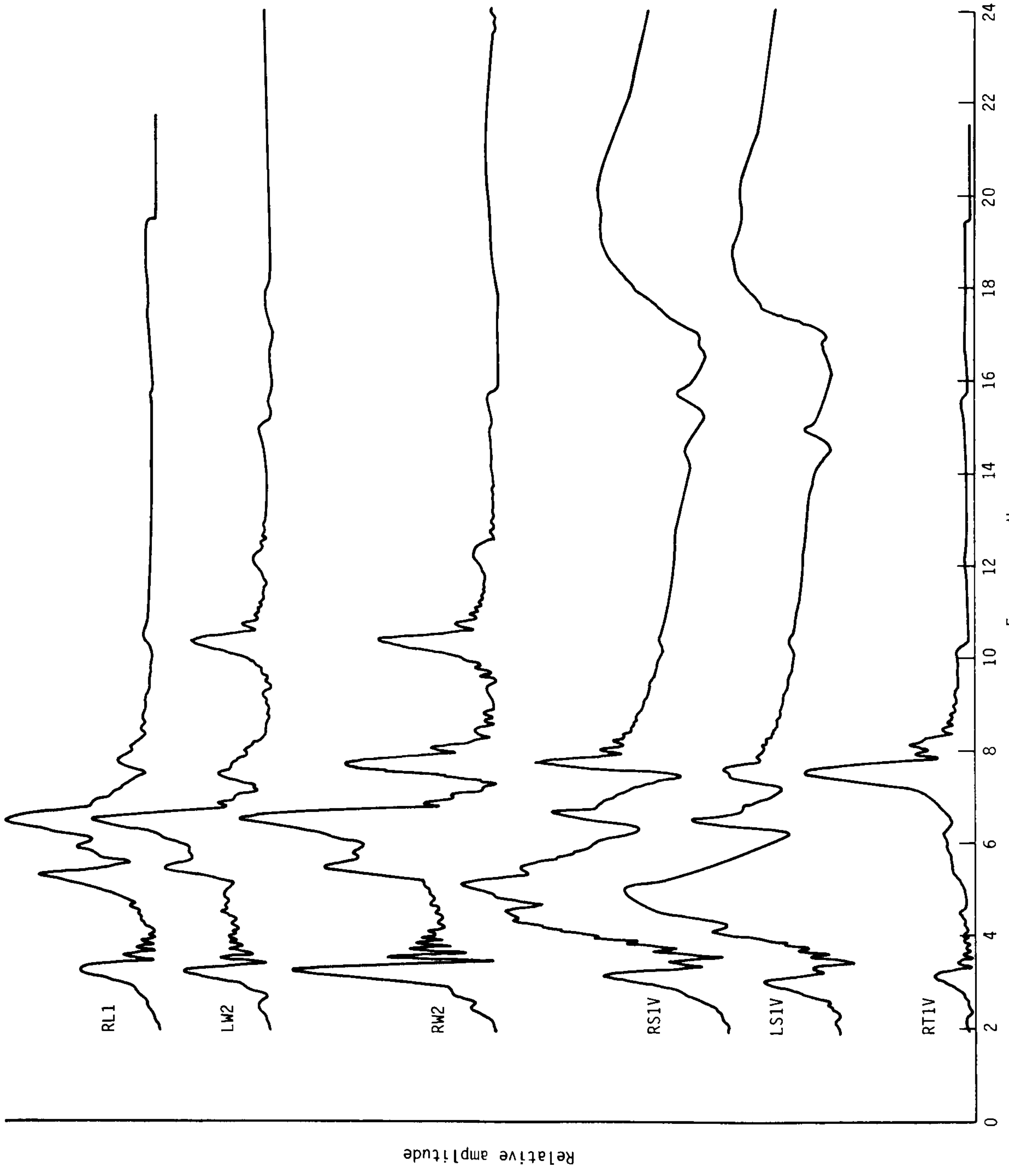


Figure A3. Frequency sweep plot for symmetric vertical excitation, GBU-8 forward shaker location, and force level of 57 lbf.

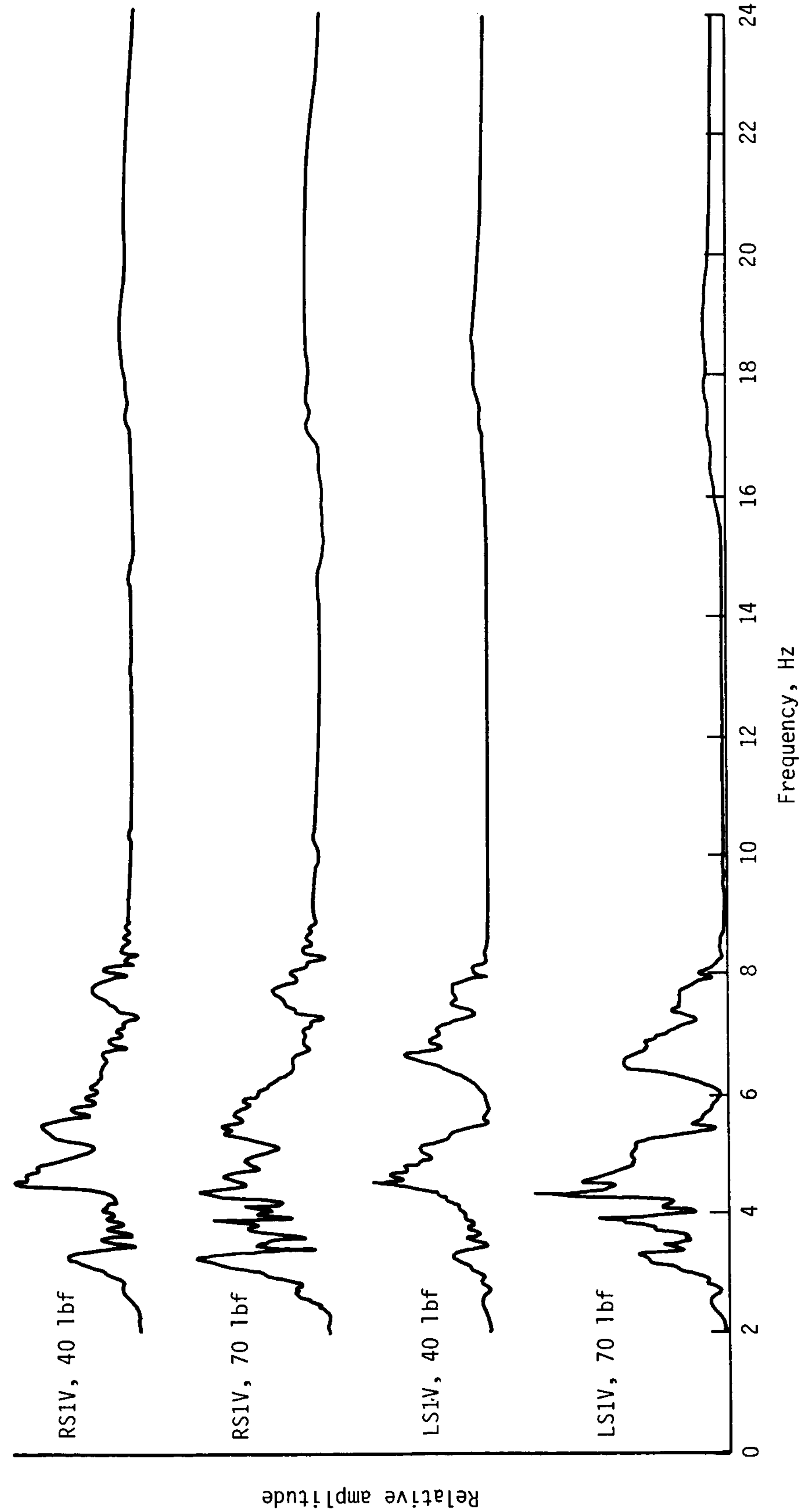


Figure A4. Frequency sweep plot for symmetric vertical excitation, GBU-8 forward shaker location, and force levels of 40 and 70 lbf.

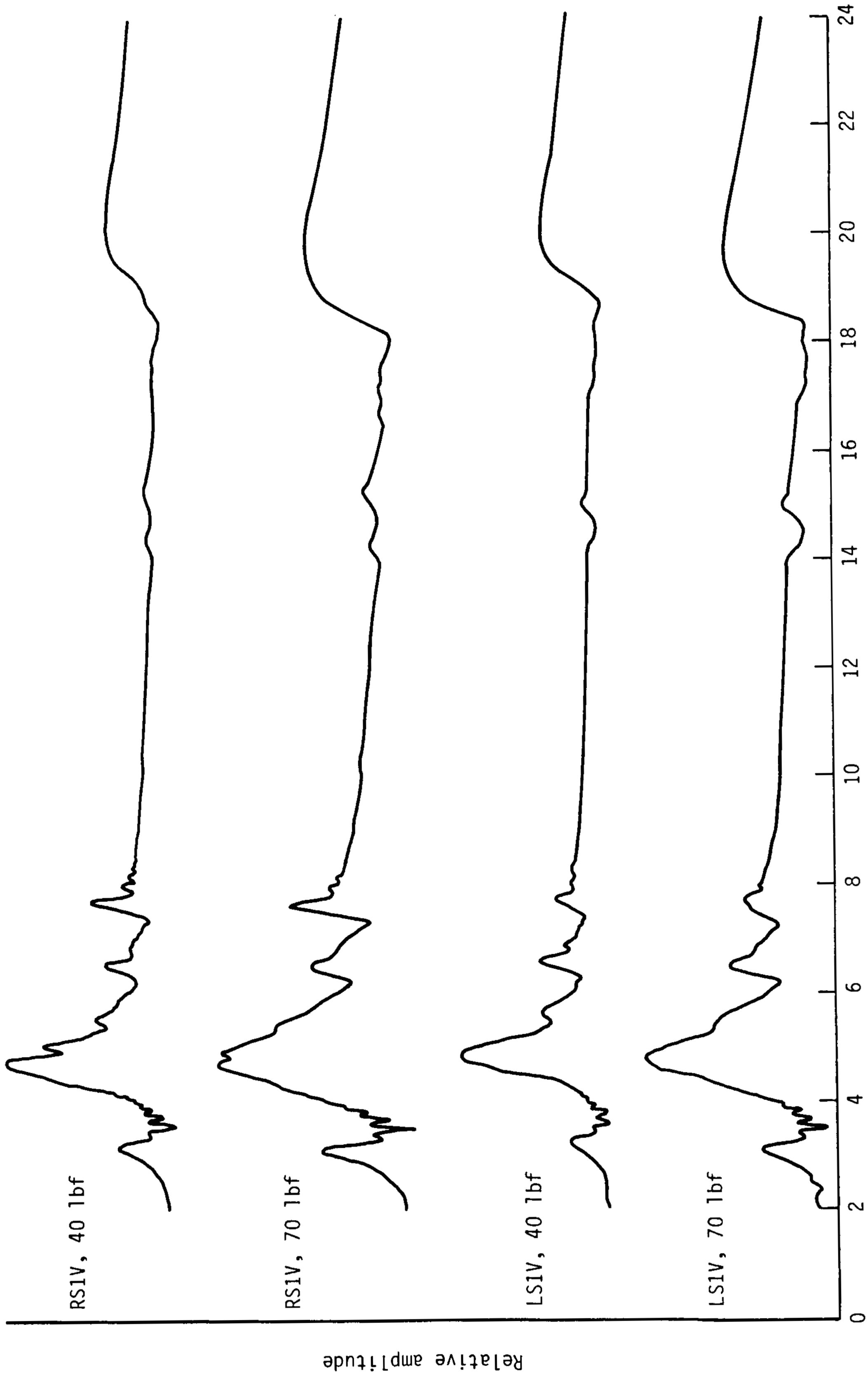


Figure A5. Frequency sweep plot for symmetric vertical excitation, pylon nose-up at limit, GBU-8 forward shaker location, and force levels of 40 and 70 lbf.

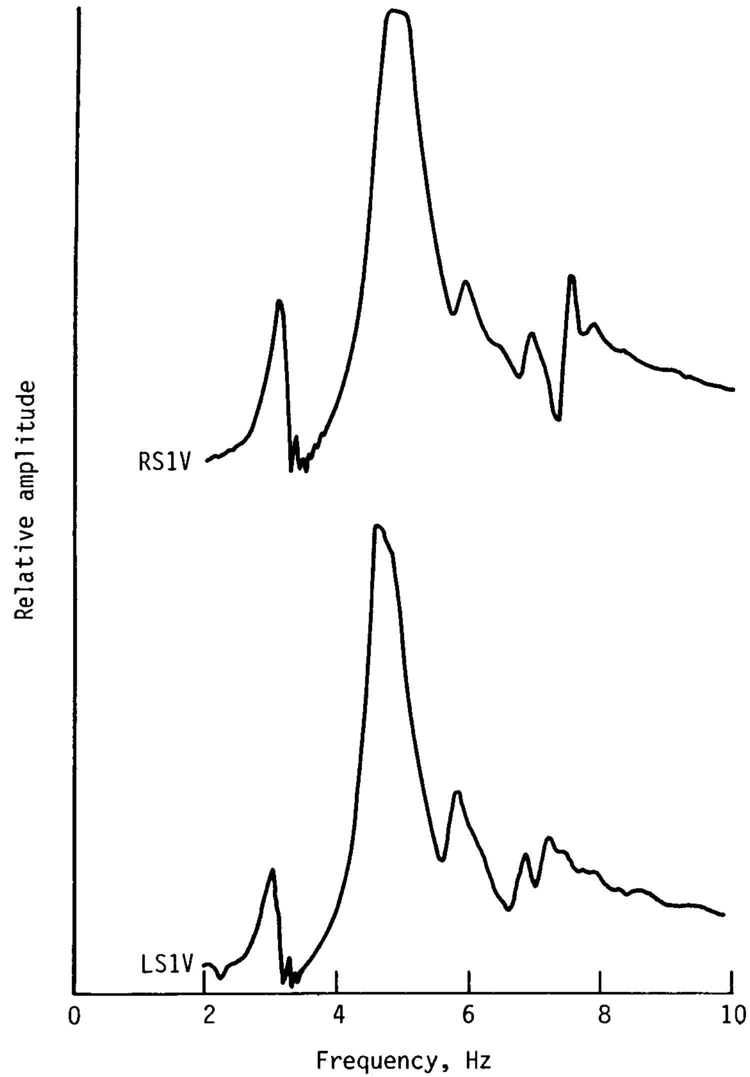


Figure A6. Frequency sweep plot for symmetric vertical excitation, pylon bound with 700-lbf preload, GBU-8 forward shaker location, and force level of 70 lbf.

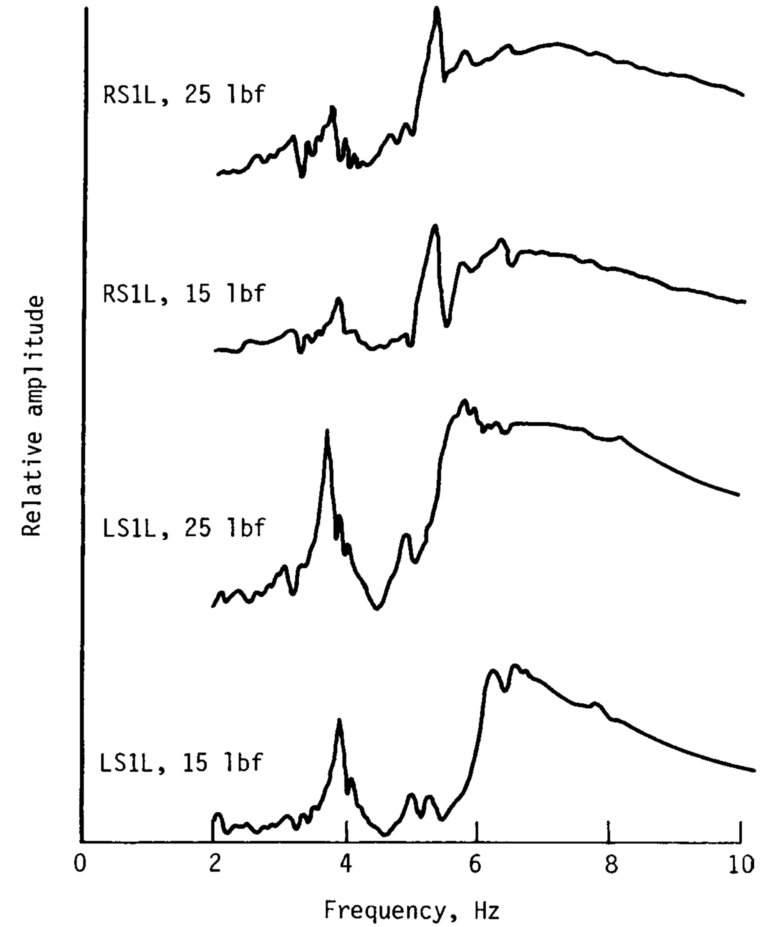


Figure A7. Frequency sweep plot for symmetric lateral excitation, GBU-8 forward shaker location, force levels of 15 and 25 lbf, and sweep rate of 0.05 Hz/sec.

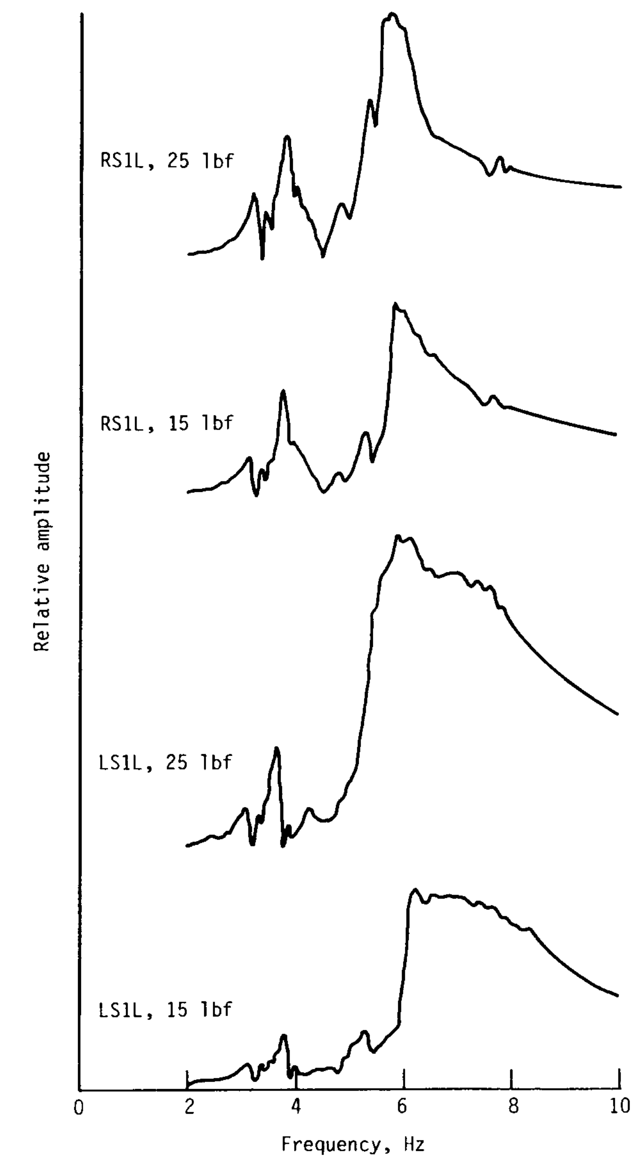


Figure A8. Frequency sweep plot for symmetric lateral excitation, pylon with 80-lbf preload, GBU-8 forward shaker location, force levels of 15 and 25 lbf, and sweep rate of 0.05 Hz/sec.

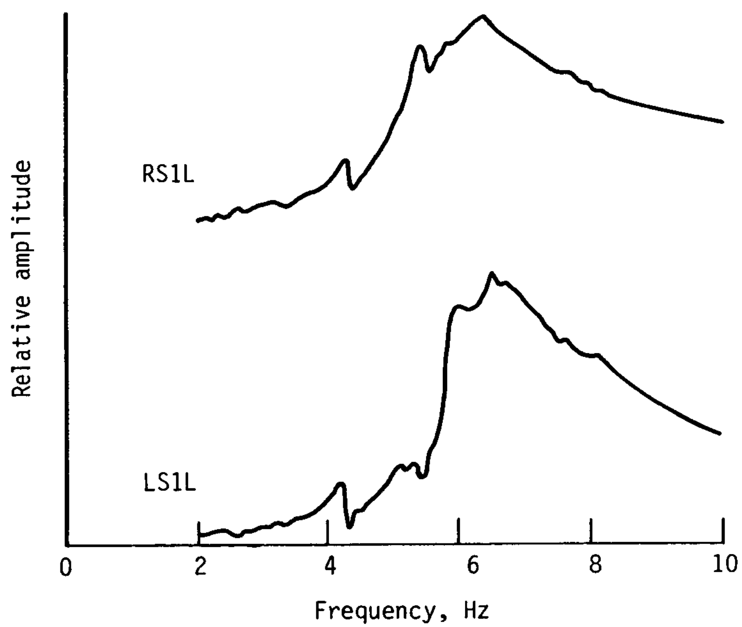


Figure A9. Frequency sweep plot for symmetric (roll) lateral excitation, GBU-8 forward and aft shaker locations, force level of 10 lbf, and sweep rate of 0.05 Hz/sec.

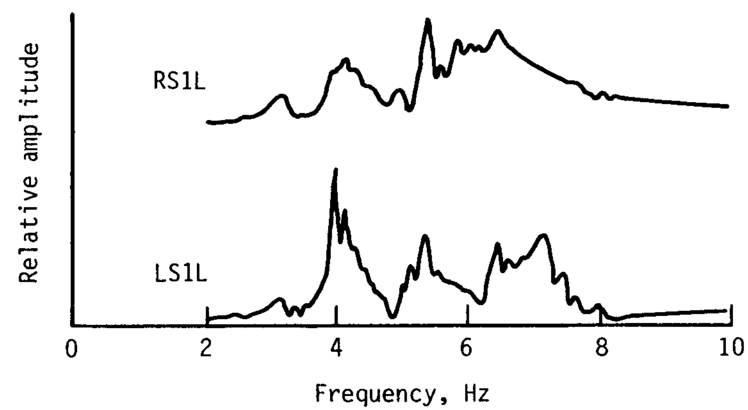


Figure A10. Frequency sweep plot for symmetric (yaw) lateral excitation, GBU-8 forward and aft shaker locations, force level of 10 lbf, and sweep rate of 0.05 Hz/sec.

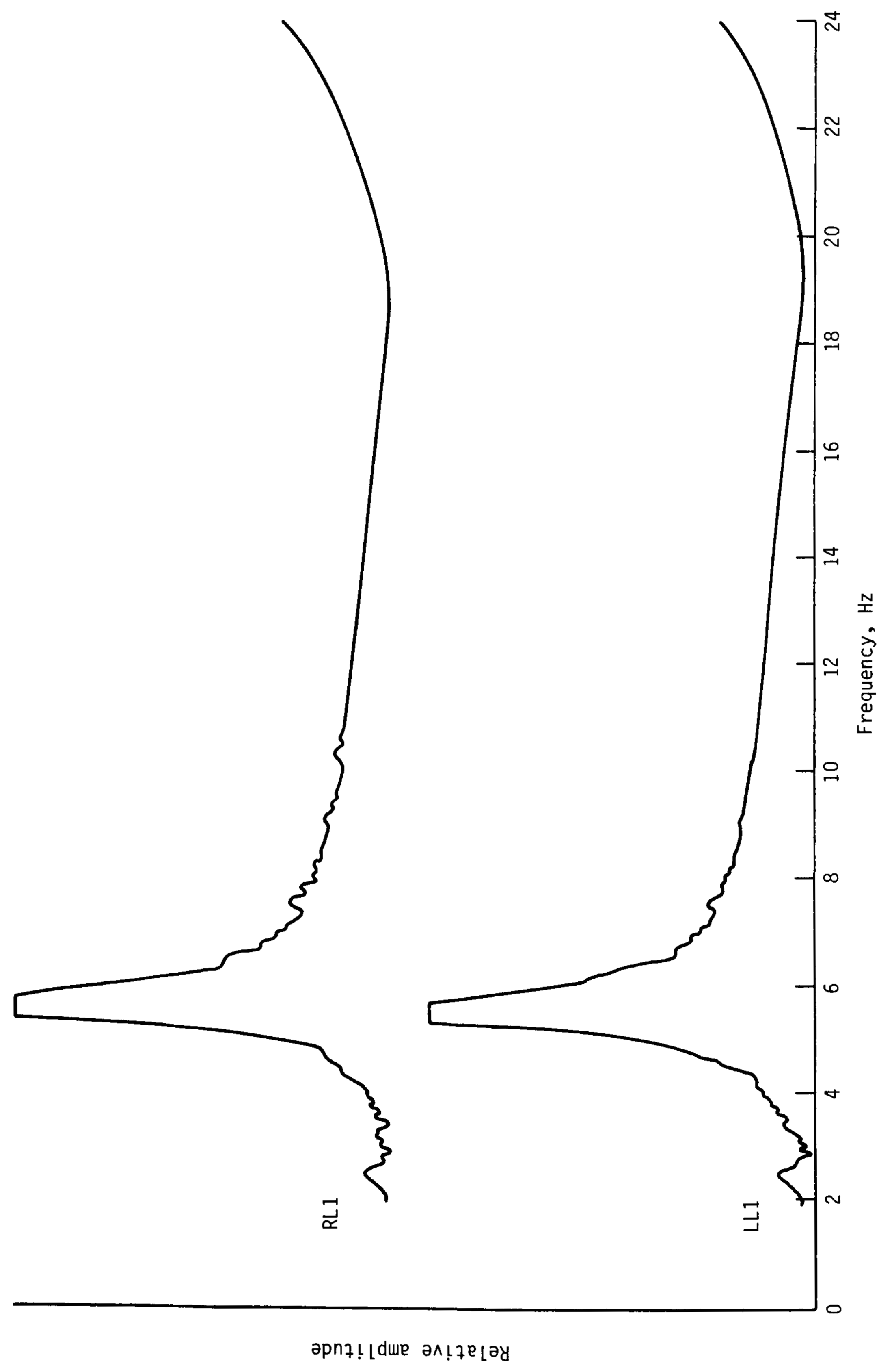


Figure A11. Frequency sweep plot for antisymmetric vertical excitation, launcher forward shaker location, and force level of 15 lbf.

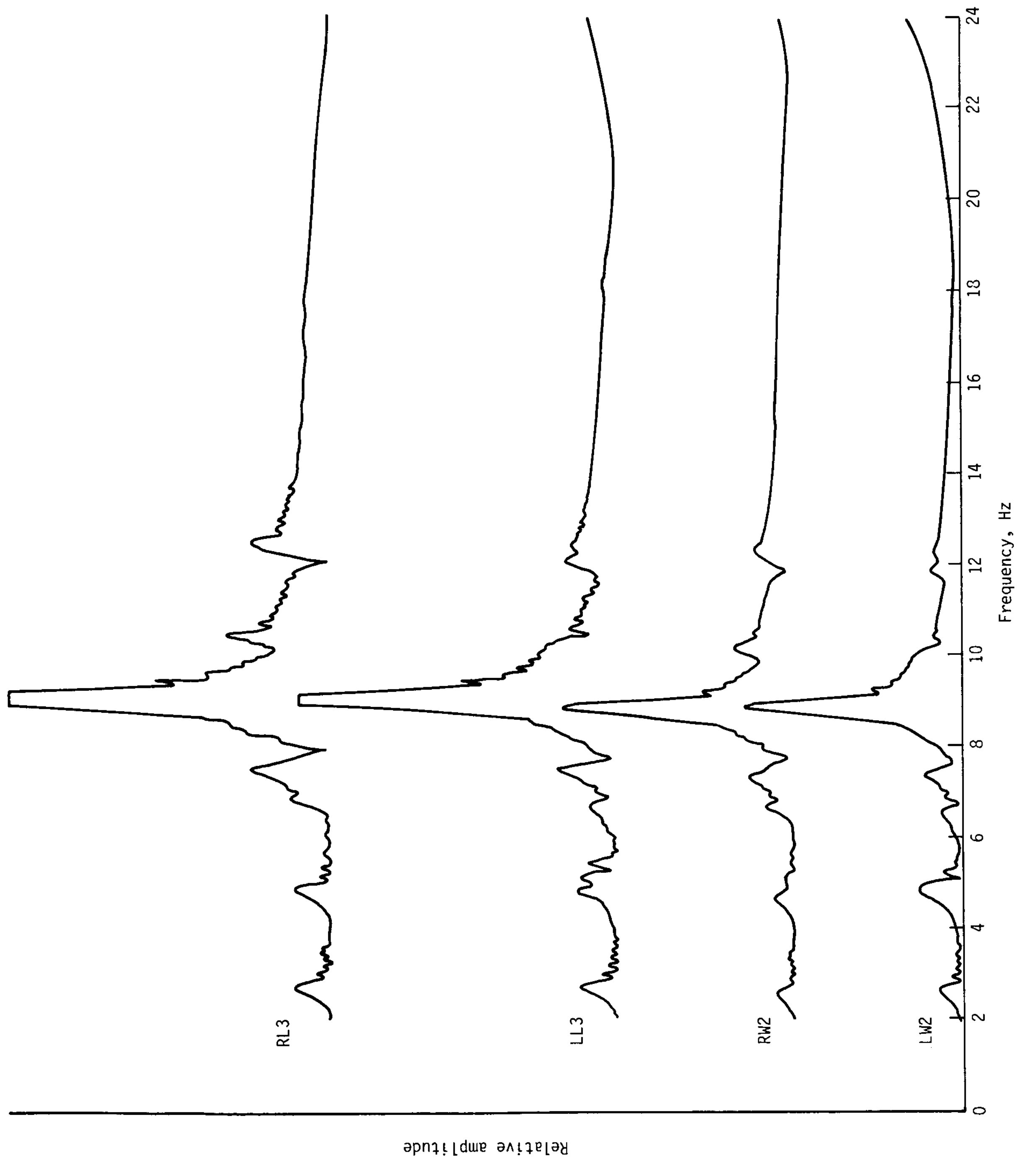


Figure A12. Frequency sweep plot for antisymmetric vertical excitation, launcher aft shaker location, and force level of 15 lbf.

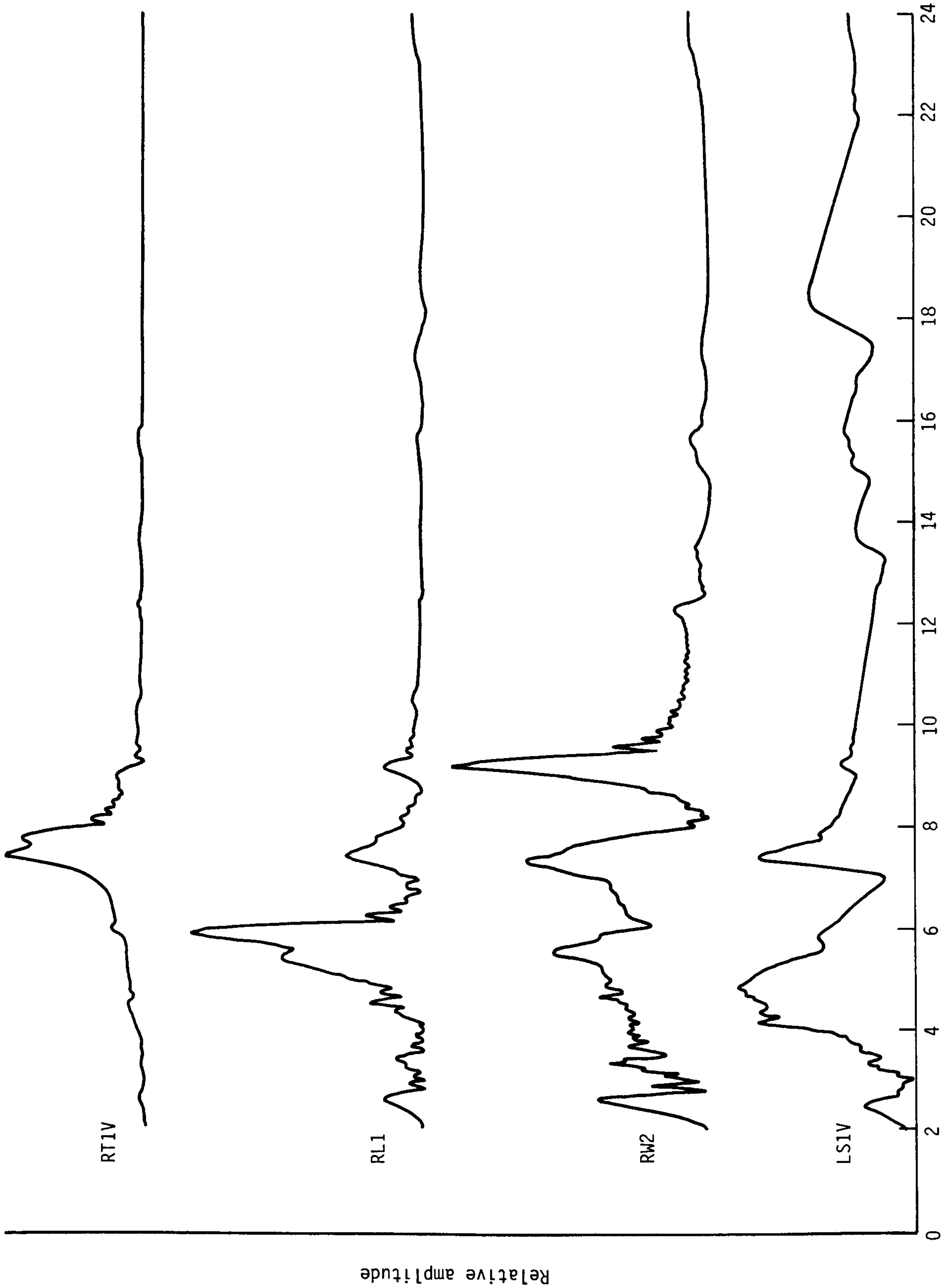


Figure A13. Frequency sweep plot for antisymmetric vertical excitation, GBU-8 forward shaker location, and force level of 57 lbf.

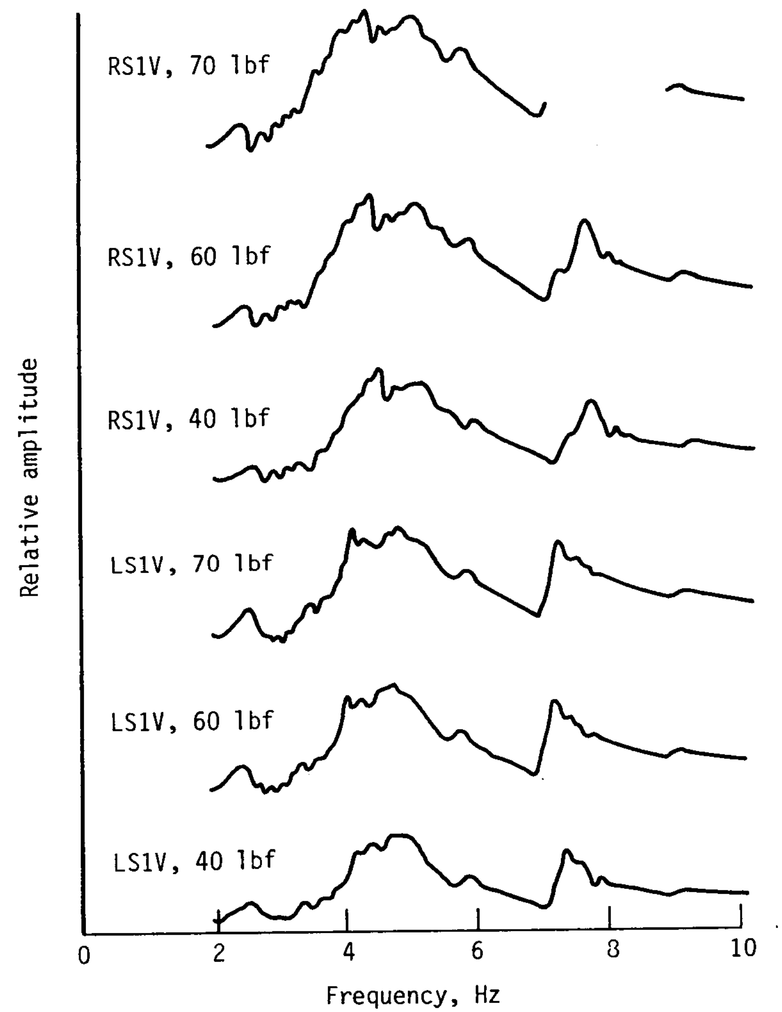


Figure A14. Frequency sweep plot for antisymmetric vertical excitation, GBU-8 forward shaker location, and force levels of 40, 60, and 70 lbf.

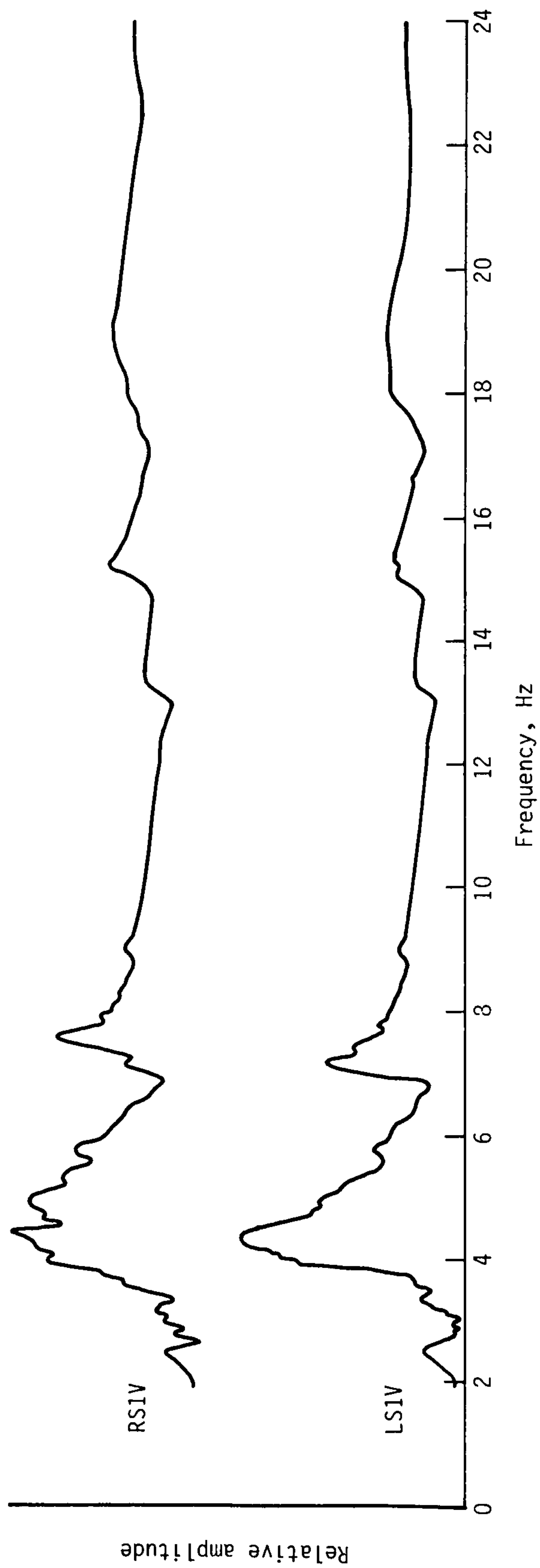


Figure A15. Frequency sweep plot for antisymmetric vertical excitation, GBU-8 forward shaker location, and force level of 70 lbf.

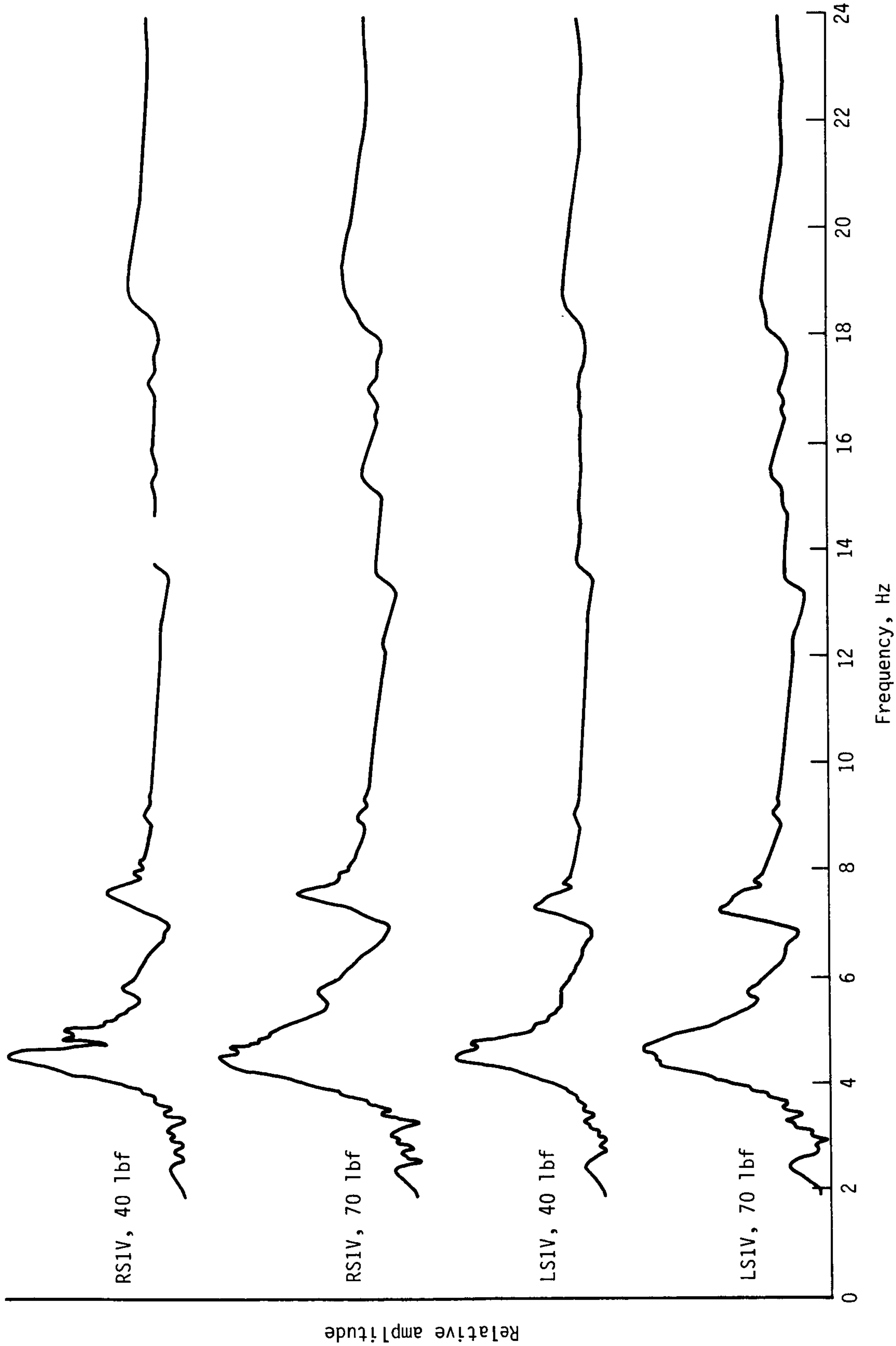


Figure A16. Frequency sweep plot for antisymmetric vertical excitation, pylon nose-up at limit, GBU-8 forward shaker location, and force levels of 40 and 70 lbf.

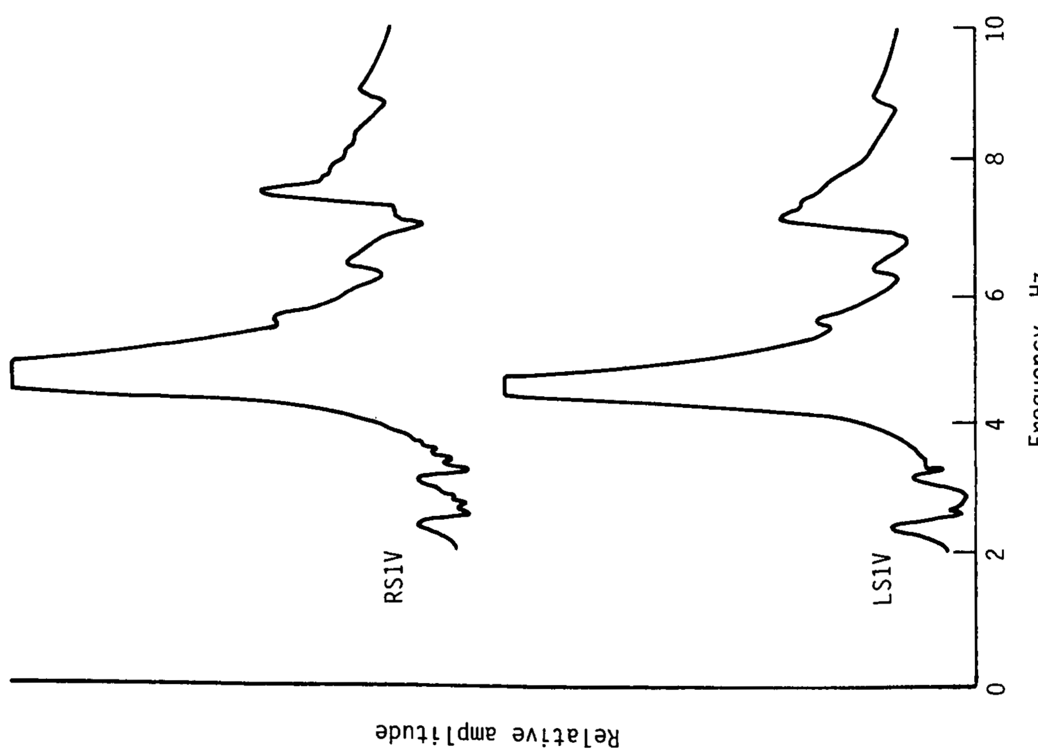


Figure A17. Frequency sweep plot for antisymmetric vertical excitation, pylon bound with 700-lbf preload, GBU-8 forward shaker location, force level of 70 lbf, and sweep rate of 0.05 Hz/sec.

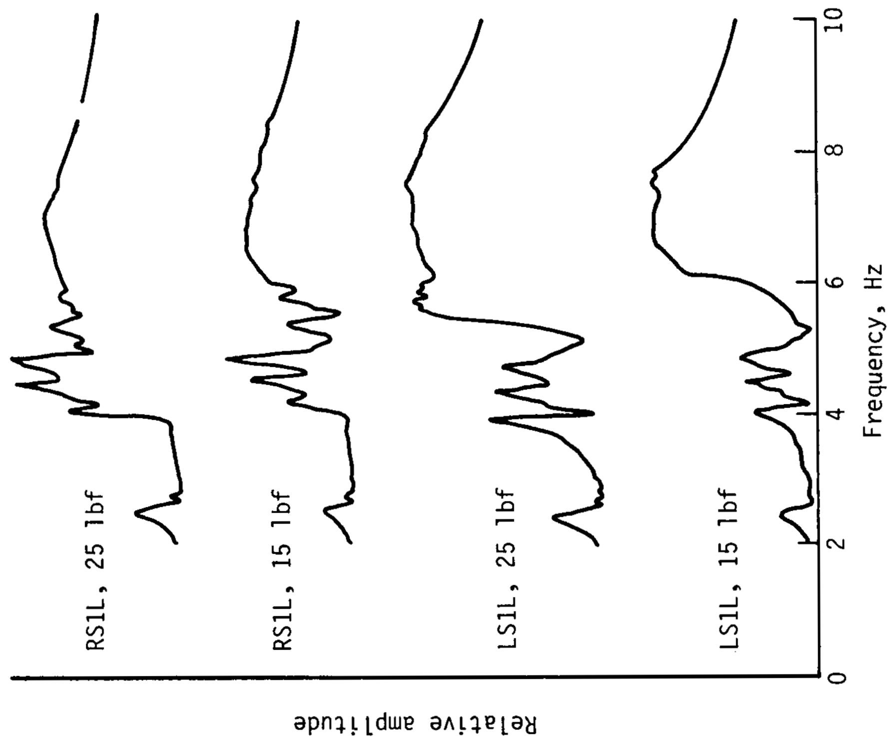


Figure A18. Frequency sweep plot for antisymmetric lateral excitation, GBU-8 forward shaker location, force levels of 15 and 25 lbf, and sweep rate of 0.05 Hz/sec.

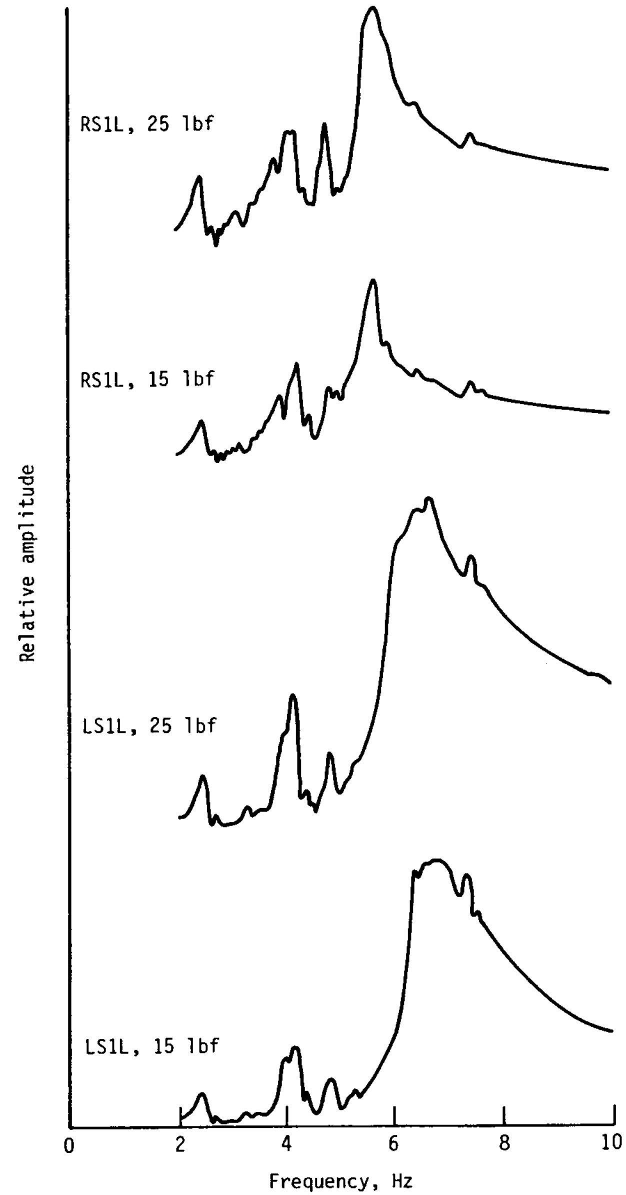


Figure A19. Frequency sweep plot for antisymmetric lateral excitation, pylon with 80-lbf preload, GBU-8 forward shaker location, force levels of 15 and 25 lbf, and sweep rate of 0.05 Hz/sec.

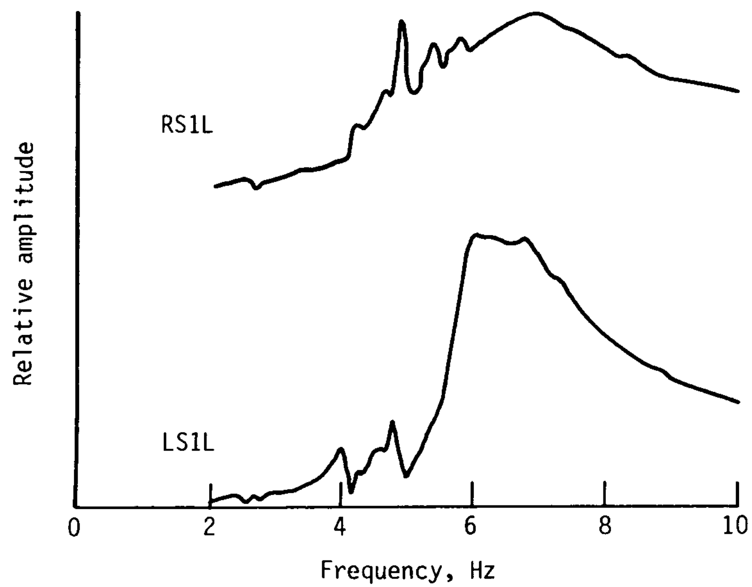


Figure A20. Frequency sweep plot for antisymmetric (roll) lateral excitation, GBU-8 forward and aft shaker locations, force level of 10 lbf, and sweep rate of 0.05 Hz/sec.

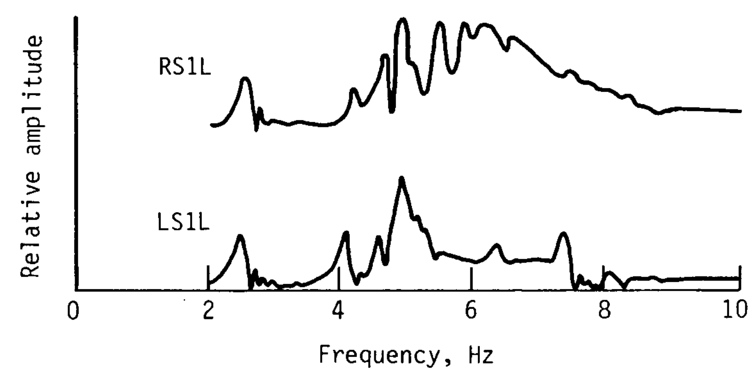


Figure A21. Frequency sweep plot for antisymmetric (yaw) lateral excitation, GBU-8 forward and aft shaker locations, force level of 10 lbf, and sweep rate of 0.05 Hz/sec.

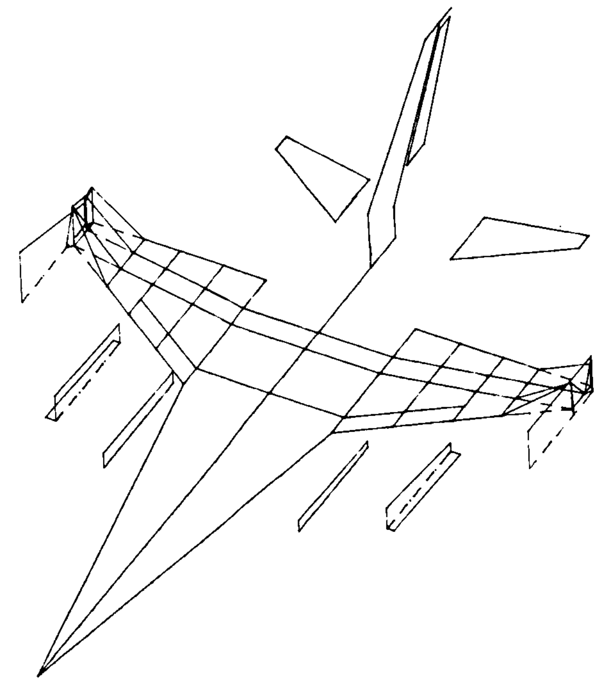
Appendix B

Mode Shape Data

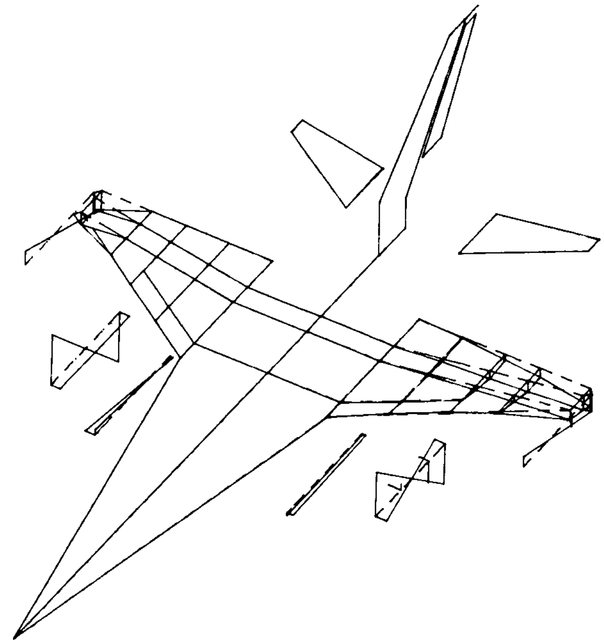
This appendix contains the measured mode shape data. The intent of the surveys was to identify the modes. Therefore, only partial surveys were accomplished for most modes. (The fully surveyed modes were the symmetric 4.08-Hz mode, and the antisymmetric 3.92- and 8.71-Hz modes.) Table B1 lists the 16 mode shape plots presented in figures B1 and B2. There are six symmetric and six antisymmetric modes and four variations given (pylon bound or unbound, left or right). The symmetric modes are given first (fig. B1(a) through fig. B1(h)) in order of increasing frequency followed by the antisymmetric modes (fig. B2(a) through fig. B2(h)) ordered in a similar manner.

TABLE B1. MODE SHAPE PLOTS

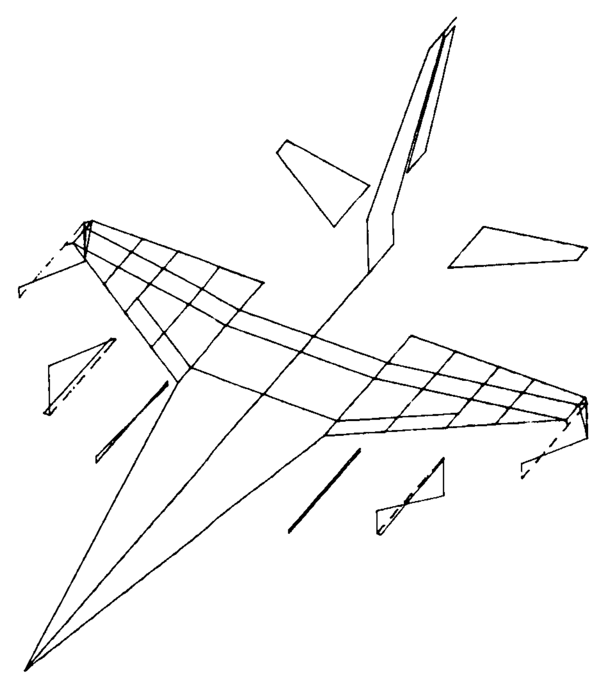
Fig.	Frequency, Hz	Symmetry	Mode
B1(a)	3.02	Symmetric	1st wing bending
(b)	4.08	↓	GBU-8 pitch
(c)	4.68	↓	GBU-8 pitch (pylon bound)
(d)	5.21	↓	GBU-8 lateral (right)
(e)	5.26	↓	GBU-8 lateral (left)
(f)	6.27	↓	Tip missile pitch
(g)	7.49	↓	Tank pitch
(h)	9.77	Symmetric	2nd wing bending
B2(a)	3.92	Antisymmetric	GBU-8 pitch
(b)	4.51	↓	GBU-8 pitch (pylon bound)
(c)	4.75	↓	1st GBU-8 lateral (left)
(d)	4.82	↓	1st GBU-8 lateral (right)
(e)	5.29	↓	2nd GBU-8 lateral
(f)	5.32	↓	Tip missile pitch
(g)	7.35	↓	Tank pitch
(h)	8.71	Antisymmetric	1st wing bending



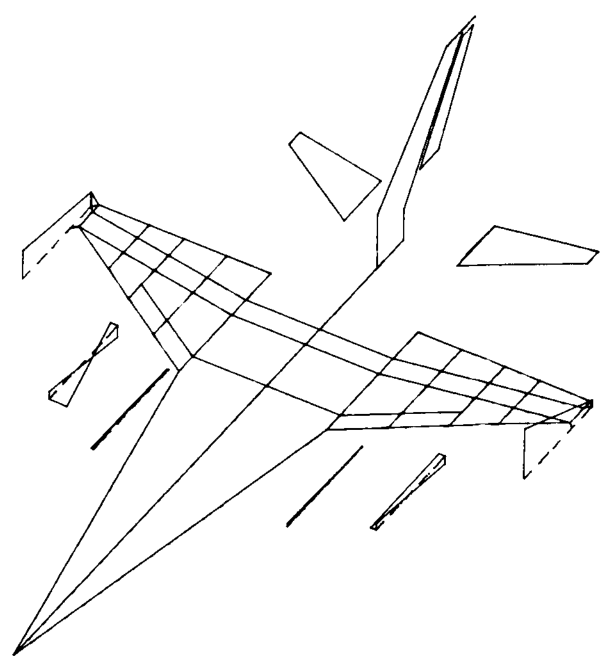
(a) Frequency = 3.02 Hz; 1st wing bending.



(b) Frequency = 4.08 Hz; GBU-8 pitch.

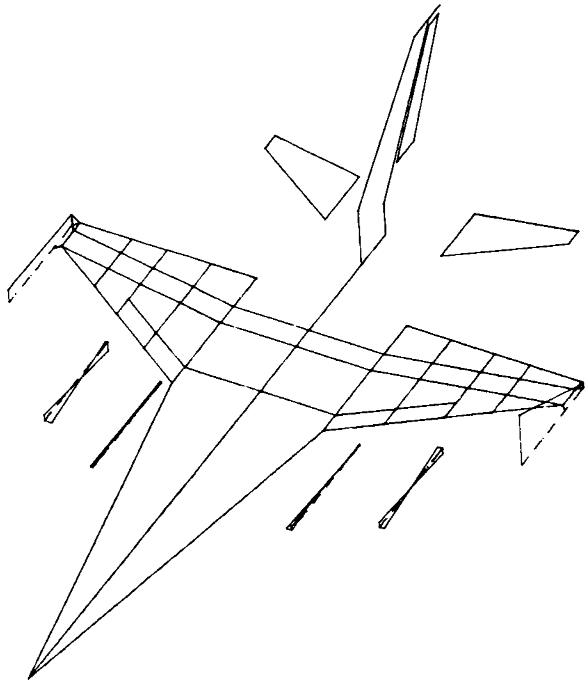


(c) Frequency = 4.68 Hz; GBU-8 pitch (pylon bound).

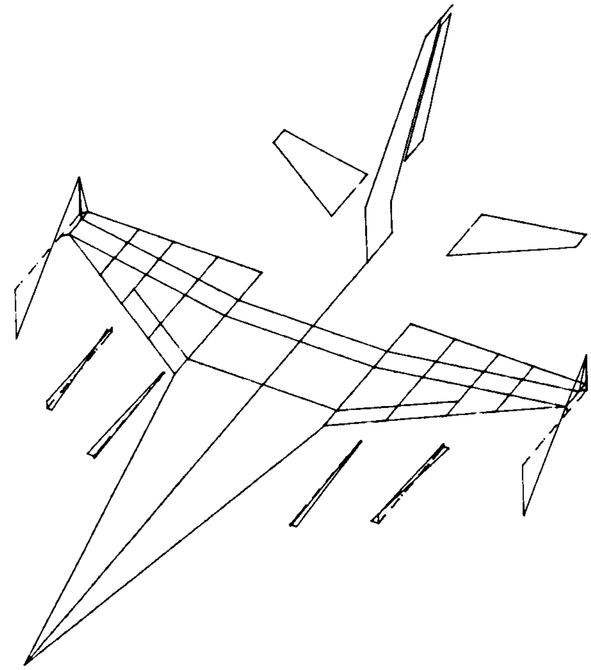


(d) Frequency = 5.21 Hz; right GBU-8 lateral.

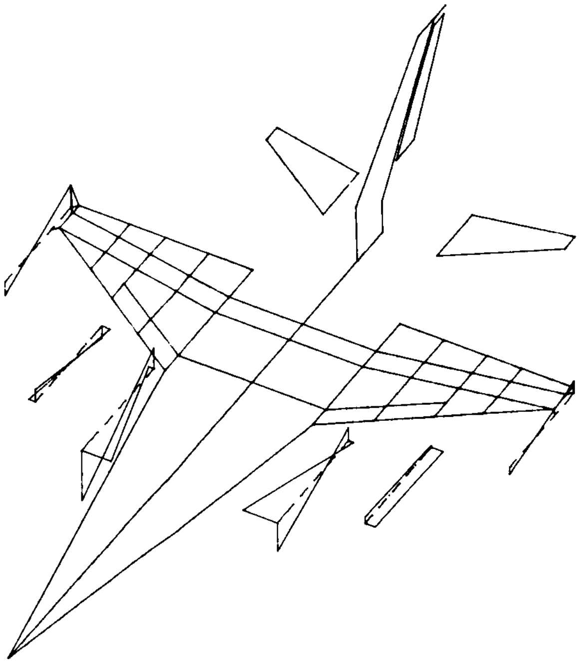
Figure B1. Symmetric mode shapes.



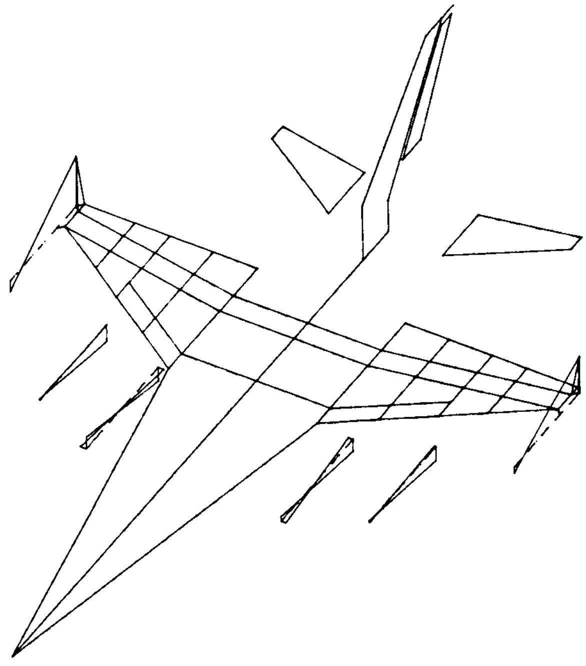
(e) Frequency = 5.26 Hz; left GBU-8 lateral.



(f) Frequency = 6.27 Hz; tip missile pitch.

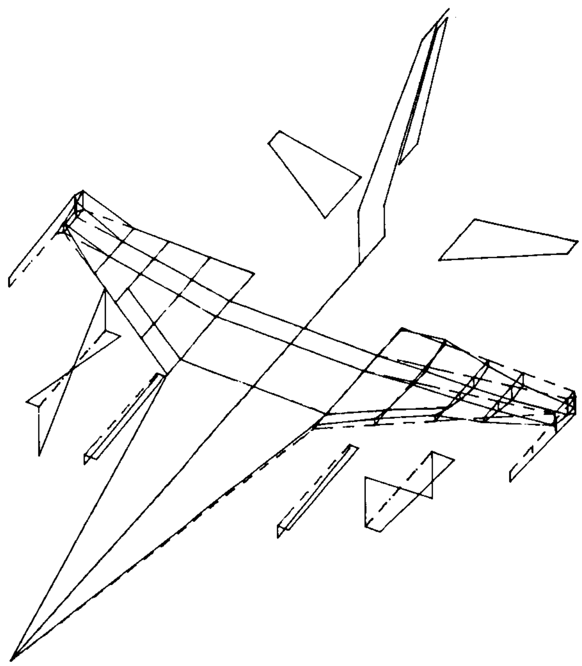


(g) Frequency = 7.49 Hz; tank pitch.

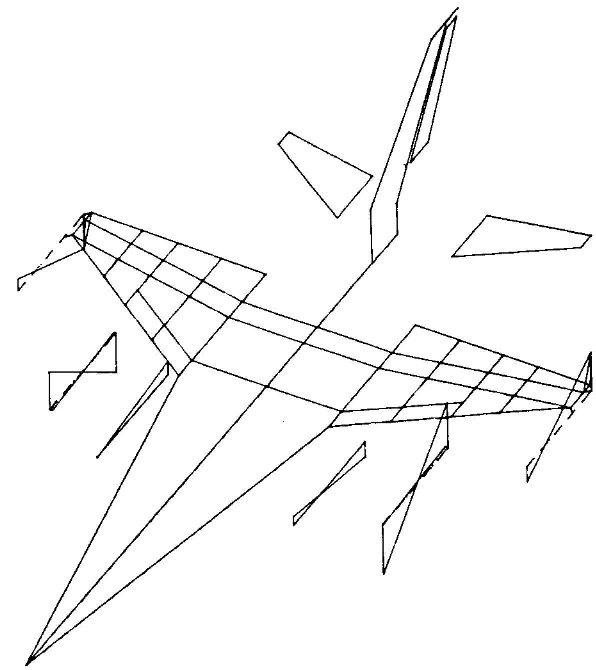


(h) Frequency = 9.77 Hz; 2nd wing bending.

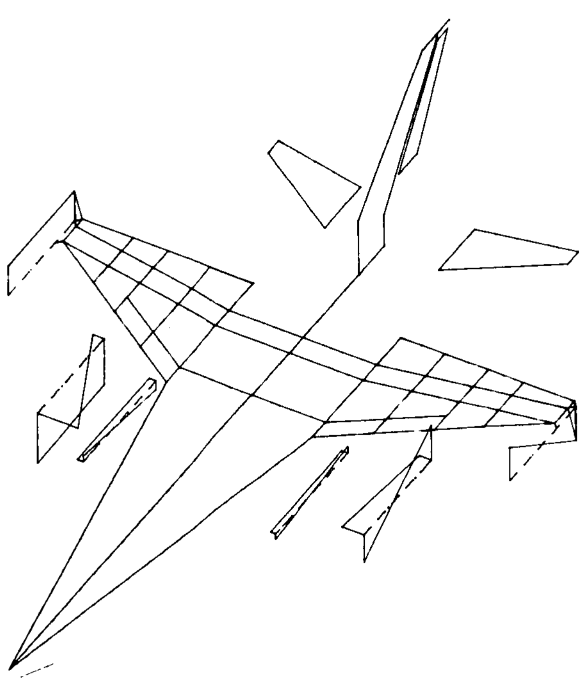
Figure B1. Concluded.



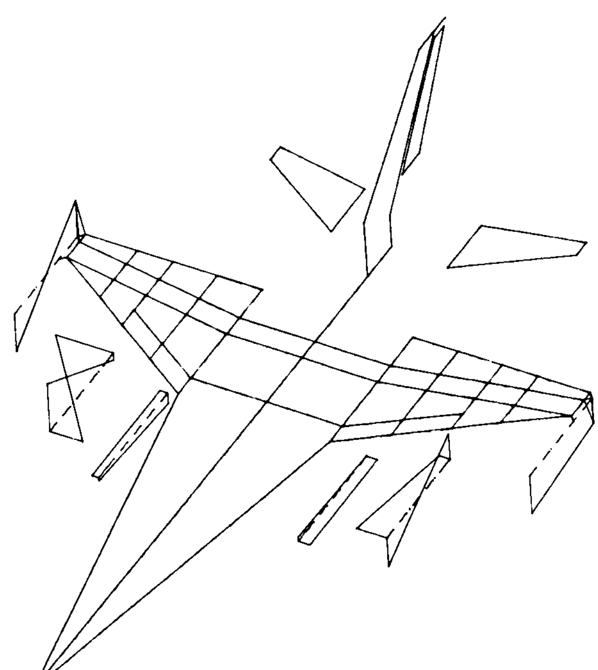
(a) Frequency = 3.92 Hz; GBU-8 pitch.



(b) Frequency = 4.51 Hz; GBU-8 pitch (pylon bound).

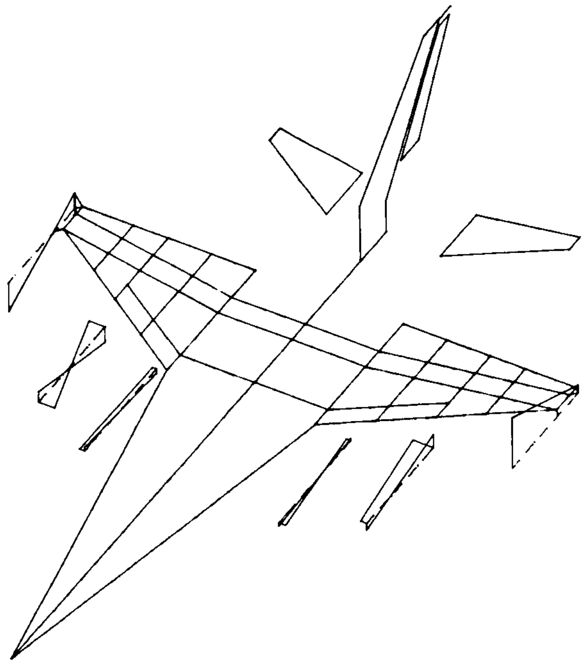


(c) Frequency = 4.75 Hz; left 1st GBU-8 lateral.

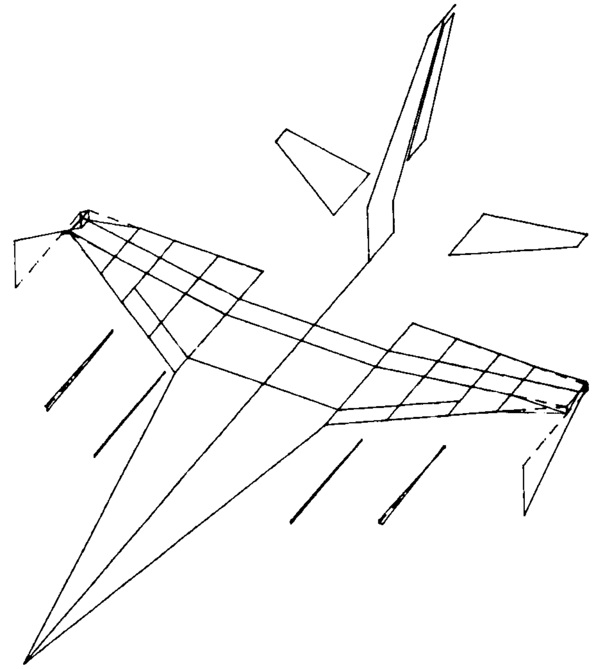


(d) Frequency = 4.82 Hz; right 1st GBU-8 lateral.

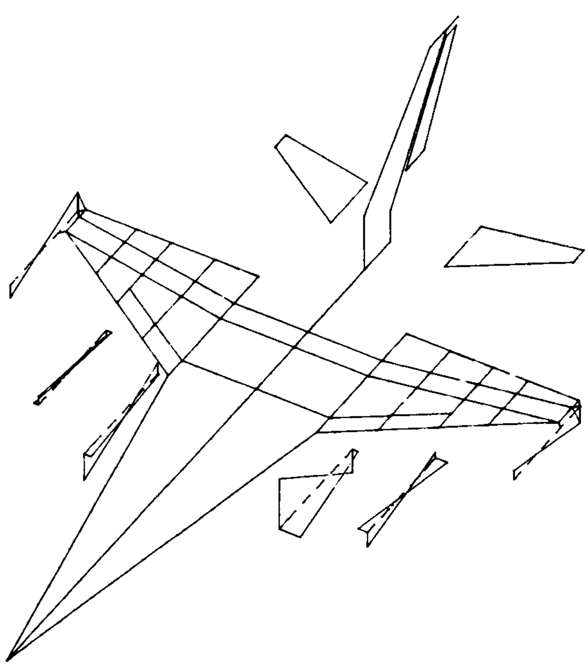
Figure B2. Antisymmetric mode shapes.



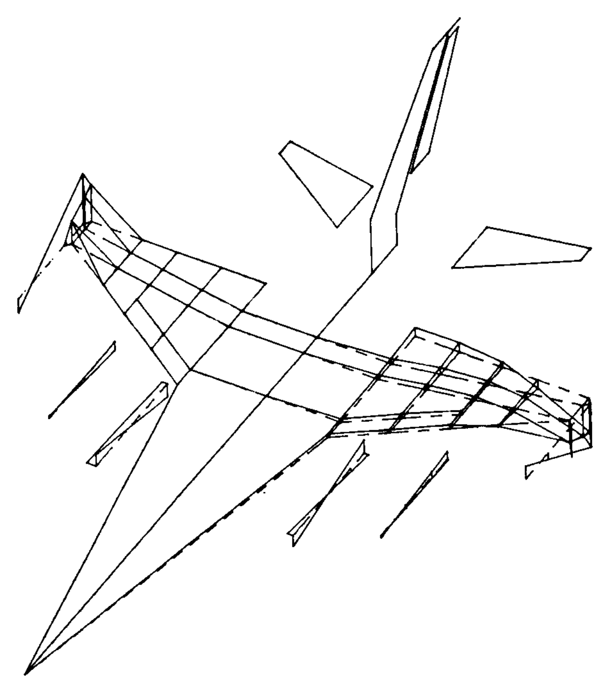
(e) Frequency = 5.29 Hz; 2nd GBU-8 lateral.



(f) Frequency = 5.32 Hz; tip missile pitch.



(g) Frequency = 7.35 Hz; tank pitch.



(h) Frequency = 8.71 Hz; 1st wing bending.

Figure B2. Concluded.

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2. Peloubet, R. P., Jr.; Haller, R. L.; and McQuien, L. J.: *Feasibility Study and Conceptual Design for Application of NASA Decoupler Pylon to the F-16.* NASA CR-165834, 1982.
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16. Abstract
A ground vibration test was conducted on an F-16 airplane loaded on each wing with a 370-gal tank mounted on a standard pylon, a GBU-8 store mounted on a decoupler pylon, and an AIM-9J missile mounted on a wing-tip launcher. The decoupler pylon is a passive wing/store flutter-suppression device. The test was conducted prior to initial flight tests to determine the modal frequencies, mode shapes, and structural damping coefficients. The data presented include frequency response plots, force effect plots, and limited mode shape data.

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